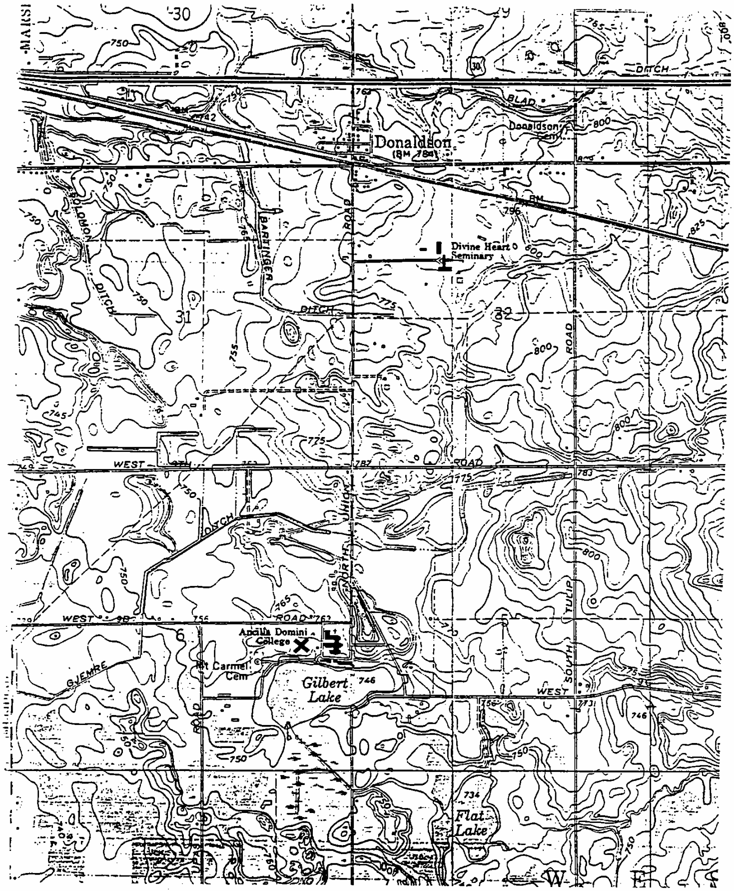
PRELIMINARY STUDY OF

GALBRAITH LAKE (GILBERT), MARSHALL COUNTY, INDIANA



A Report for
Ancilla Domini Convent and College

January 1997

Lake and River Enhancement Program
Indiana Department of Natural Resources

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EXECUTIVE SUMMARY

This report gives the results of a preliminary study of the chemical, physical, and biological condition of Galbraith Lake, its one permanent and one intermittent tributary, and the outlet stream in Marshall County, Indiana. Further study, management alternatives, and recommendations for lake rehabilitation are presented.

Condition of Galbraith Lake and Surrounding Streams

Quality of Galbraith Lake apparently has improved from an extremely eutrophic lake in which winter fish kills were relatively common to a more functional lake that approaches average conditions for similar lakes in the surrounding region. A summary of the historical and current condition of the lake, tributaries, and outlet is presented below.

1. Soils of the Galbraith Lake watershed consist of sand, loam, and muck. Highly Erodible Land (HEL) acreage constitutes approximatley 12 % of the total land acreas in the watershed. Most of the HEL area is currently protected by vegetative cover. The region around the Galbraith Lake watershed supports a number of endangered, threatened, and rare species and community types, including muck flat and fen wetlands, sand flatwoods forest, and mesic prairie. The watershed includes several areas that would be physically amenable to wetland and forest habitat rehabilitation.

2. During all summers for which data were available (1970-1995), thermal and chemical stratification occurred, such that depths below 7 to 13 feet were uninhabitable for most fish and other organisms. For two years (1970 and 1995), surface temperatures were above 80 ^{O}F in depths with sufficient oxygen to support most life. High temperatures can exacerbate toxicity of some chemicals and cause elevated metabolic rates in aquatic animals, decreasing energy available for growth.

3. High surface pH levels and low total alkalinity indicated high aquatic plant productivity, most likely algal growth, for the years 1973 to 1976. Chemical conditions at the surface of the lake suggested a decrease in plant productivity during more recent years (1991, 1995).

4. Water clarity in Galbraith Lake was extremely poor through 1986, ranging from one to two feet in depth. Light levels during these years would have limited rooted aquatic plant growth to depths of three to six feet. Secchi disk readings since 1991 have shown significant improvement at equal to or greater than four feet in depth. Clarity would have to increase by another 40 percent to reach the average for Marshall County lakes of a similar size (16-40 acres) at 5.8 feet.

5. Bluegreen algae can cause noxious blooms, particularly in small shallow lakes like Galbraith Lake. Bluegreens constituted less than half of the algal population during late summer, but expanded to over 80 percent by fall, possibly in response to nutrient resuspension during fall turnover. Microscopic animals (zooplankton) which eat some forms of algae, excluding bluegreens, decreased towards fall.

6. Shoreline vegetation and emergent plants in the lake appeared to offer fairly extensive protection to the shoreline and shallow zones of the lake. Purple loosestrife occurred around the public access site. Preventing the spread of this exotic species will be critical to the plant community around the lake. Rooted aquatic plants showed low diversity and coverage, probably in response to low light levels and high turbidity in the past. The aquatic plant community should increase in diversity and coverage as water quality improves.

7. Historically, Galbraith Lake supported a reasonable sport fishery. However, declining water quality, resulting in periodic winter fish kills, and intrusion by carp contributed to poor fishing through the 1970s. Attempts at renovation and restocking of sport fish in 1972, 1980, and 1992 have met with limited success. Future renovation efforts will depend upon continuing management strategies that reduce sediment and nutrient inputs.

8. Phosphorus, ammonia, and organic nitrogen were all unusually high in deeper lake water during late summer and fall. Sources of nutrients for Galbraith Lake include recycling of nutrients attached to bottom sediments during fall turnover, as well as continuing inputs of nitrates and total phosphorus from the east inlet and storm drains. Nitrate level in the storm drain was 9 mg/l, approaching the drinking water limit of a maximum of 10 mg/l nitrate. Nutrients decreased in the outlet stream from immediate exit from the lake to a downstream position below the pasture on the south side of the lake.

9. Overall quality of Galbraith Lake has improved dramatically over the past decade. Previous to 1986, the lake had the highest possible eutrophication index (EI) of 75 points, ranking among the worst lakes in the state of Indiana. By 1990, the EI had dropped to 39, improving the lake management class from III (poor quality) to II (intermediate quality). In 1995, the EI had remained at 33 points in late summer, but was estimated to increase to 43 points at turnover in early fall.

Recommendations for Lake and Tributary Management

Sediment and nutrient sources to Galbraith Lake are located immediately around the lake and in the watershed. The following list summarizes potential alternatives for improving water quality in the lake by controlling sediment and nutrient inputs.

1. Reducing sediment and nutrient inputs by: 1) maintaining aquatic vegetation in shallow bays on the east and west ends of the lake; 2) rehabilitating the channelized outlet stream and associated wetlands; 3) routing wastewater discharge through a wetland and

into the outlet stream on the south side of the lake; 4) providing adequate protection from cattle for restoration measures around the outlet stream and on the southwest side of the lake; 5) controlling siltation and nutrients in the eastern inlet through construction of a sediment trap or wetland area; and 6) identifying and minimizing nutrient sources in storm water drains

2. Removing nutrients from deeper water by pumping deep water from the lake to irrigate grounds and gardens around Ancilla Domini Convent and College.

3. Avoid mixing of deep and surface water by: a) maintaining mature forest and planting saplings around the lake, particularly on the east and west exposures; and b) using only nonmotorized watercraft in shallow parts of the lake and limiting operation of power boats to low horse power motors at trolling speed over deeper waters.

4. Aeration of deeper water and sediment sealing with alum would lock phosphorus into sediments, making it unavailable for use by algae and aquatic plants. Both options are fairly expensive and should be considered after pursuing all other avenues.

5. Future research on the lake could include: a) continued participation in the IDEM Volunteer Lake Monitoring Program to provide an ongoing data on water clarity, algae concentration, and nutrients; b) chemical testing of tributaries and storm drains after a series of heavy rains; c) biological sampling of macroinvertebrates in the main tributary and outlet stream; d) a complete survey of aquatic plant species distribution and abundance; e) testing for fecal coliforms at the public access site, boat dock, and outlet stream; f) identification of nutrient sources in the storm drains; and g) sediment analysis for phosphorus content.

1.0 INTRODUCTION

Galbraith Lake, also known as Gilbert Lake, has a water surface that covers 37 acres and has a watershed of approximately 182 acres with a lake to watershed ratio of 4.9:1. The shoreline is owned by the Ancilla Domini Convent and College and is undeveloped except for the institution on the north shore and a small sewage treatment plant on the south shore. The lake is located approximately 1.6 miles (2.6 km) south of Donaldson in Marshall County, Indiana. In 1964, hydrographic surveys measured the deepest point in the lake at 29 ft with a mean depth of 13 ft and volume of 488 acre ft. The water level varies by about 1 ft around 746.40 ft. Lake sediments consist mostly of muck.

The lake has one well-defined intermittent inlet stream on the east side and a poorly defined channel draining a small wetland area on the west side. The unnamed outlet stream is channelized for the first 0.3 mi (0.5 km) and drains into Flat (Mud) Lake after 1.7 mi (2.7 km). Flat Lake is on a chain of headwater lakes on Eagle Creek which drains into the Yellow River just east of Knox in Starke County. The system is part of the Kankakee River basin.

2.0 METHODS

Watershed maps for topography and forested land use were redrawn or copied from the most recent (1972) U.S. Geological Survey 7.5 minute topographic map at a scale of 1:24,000. Current land use activities were determined and soil maps created by the Marshall County Soil and Water Conservation District. Soil maps were completed with information from the Marshall County Soil Survey. The amount and location of highly erodible soils (HEL) were determined.

Water samples and in-lake measurements were obtained in 1995 during late summer on August 16 at the deepest point of the lake and in early fall on September 22 from the end of the boat dock on the north side of the lake (Figure 2.1). All parameters needed to calculate the Eutrophication Index (EI) were measured in the lake. This index was developed by the Indiana Department of Environmental Management to classify the water quality status of lakes. Calculation of the index is described in the Appendix. Tributaries were sampled on August 16 in a pool below the road culvert on the east inlet, in a pool of standing water near the mouth of the west inlet, and on the upstream side of the road at the lower end of the outlet; on September 22, the west inlet was dry and an additional sample was taken in the upper outlet immediately below the lake (Figure 2.2).

Profiles of temperature and dissolved oxygen were obtained with a YSI Model 51B Dissolved Oxygen Meter. Orthophosphate and dissolved oxygen were measured using the Hach Surface Water Test Kit Model 25598-00. Nitrates, ammonia, total phosphorus, and organic nitrogen (Total Kjeldahl Nitrogen or TKN) were tested within 24 hr from samples placed on ice in the field and preserved in the laboratory at the Indiana State Board of Health (ISBH).

Plankton samples were collected on August 16 over the deepest point of the lake with a 12 inch diameter, 63 micron mesh tow net. Two separate tows were made, one from a depth of 5 ft and another from the beginning of the thermocline at 11 ft. On September 22, a single tow was made from a depth of 5 ft. The probably constitution of a deeper tow was assumed for purposes of estimating the fall EI.

Data on flora and fauna in the Galbraith Lake region were from several sources. A listing of aquatic and shore plant species was made by direct observation in July, 1995. Additional qualitative observations made by fisheries biologists before and after the fishery renovation were included in this report. Plant distributions were not determined quantitatively. No direct sampling of aquatic plants was conducted. Data on the fish community were taken directly from fisheries reports submitted by Bob Robertson of Bass Lake State Fish Hatchery, IDNR. Data on threatened, endangered and rare species were from the Indiana Heritage Trust Database (Ron Hellmich, Division of Nature Preserves, IDNR, January 2, 1997).

Figure 2.1. Location of in-lake sampling sites at Galbraith Lake. The deepest part of the lake was sampled on August 16. Lake water at the end of the boat dock on the north side of the lake was taken on September 22, 1995.

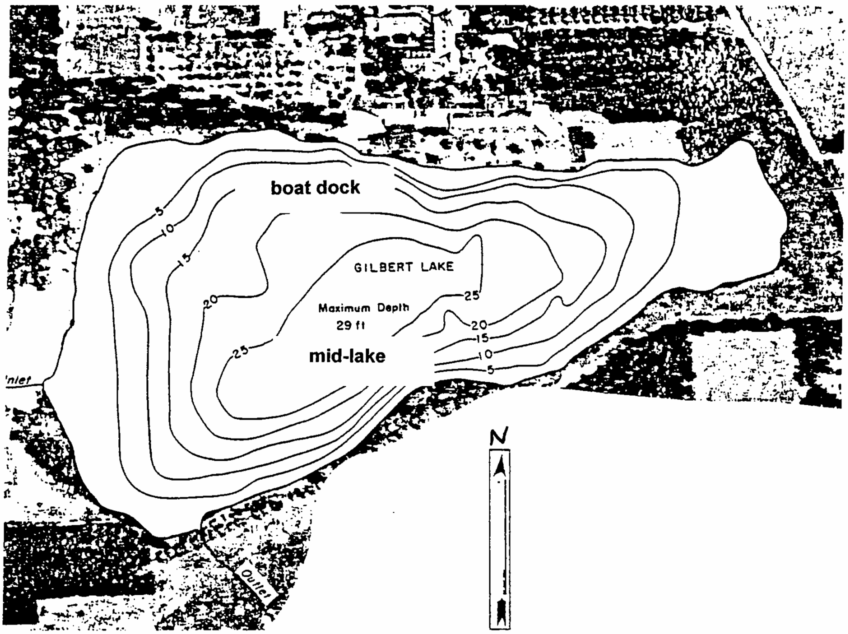
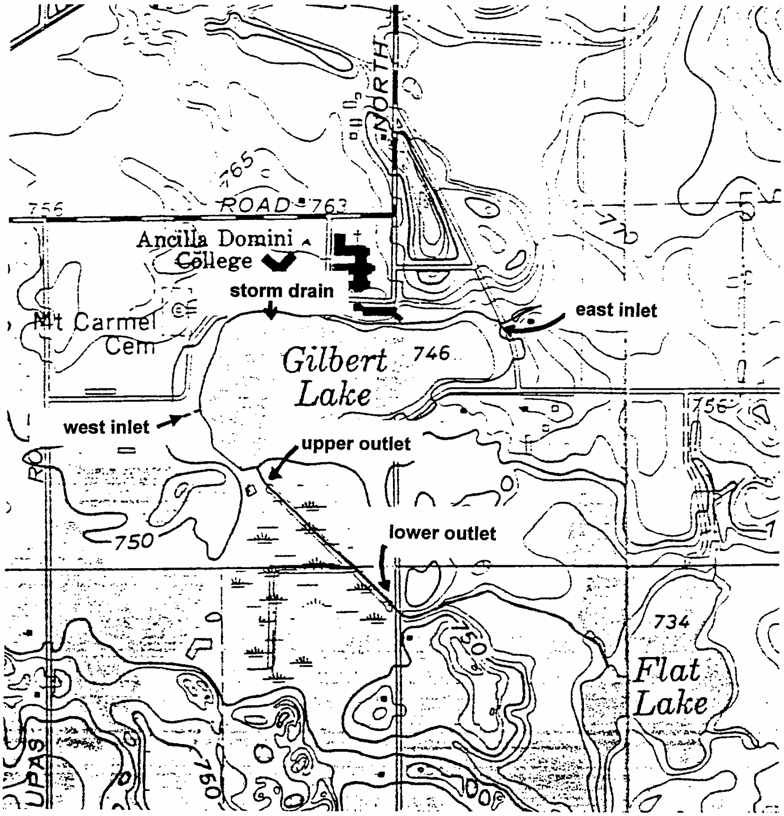


Figure 2.2. Location of tributary sampling sites around Galbraith Lake. The upper outlet area was not sampled on August 16, 1995. The west inlet was too dry to sample on September 22, 1995.



3.0 Watershed Soils and Land Use

Watershed soils and land use are primary factors in determining the water quality status of lakes. The watershed of Galbraith Lake lies completely in Marshall County. A detailed account of the soil associations, erodibility, and current land use follows.

3.1 Soils and Limitations

The soils of Marshall County formed in glacial till, sand and gravel outwash, and organic deposits. Soils that formed in till are well drained to very poorly drained and are medium or moderately fine textured. Soils that formed in outwash are medium or moderately coarse textured and are very poorly drained to excessively drained. Organic soils consist of muck and peat and are very poorly drained. A soil association is a landscape that has a distinctive proportional pattern of soils. It normally includes one or more major soils and at least one minor soil and is named for the major soil(s). The following information regarding general soil associations is from the Marshall County Soil Survey, 1980.

Two general soil associations are found around Galbraith Lake (Marshall County Soil Survey). From a north-south line bissecting the eastern tip of the lake, the soils are in the Riddles-Metea-Wawasee assocation characterized by deep, nearly level to strongly sloping, well drained, moderately coarse textured and coarse textured soils on moraines. This map unit is suited to cultivated crops, hay, and pasture. The major soils in this unit are well suited to trees, sanitary facilities, and building sites. Slope and the moderately fine texture of the suboil are the main limitations, requiring various conservation practices to manage soil erosion. The rest of the lake shore and watershed lying to the west of this line consist of soils in the Plainfield-Chelsea-Tyner association with deep, nearly level to strongly sloping, excessively drained and well drained, coarse textured soils on outwash plains. This map unit is poorly suited to cultivated crops and sanitary facilities, but is well suited to building sites. Various conservation practices can be applied to compensate for the main limitations of slope, droughtiness and poor filtering qualities.

Knowledge of individual soil types in an area is essential for developing appropriate conservation and land use plans. Soil types, acreage, percent of watershed covered by each soil, and erodibility are listed in Table 3.1. Erodibility is a function of: 1) soil texture; 2) length and degree of slope; and 3) presence of erosive forces (e.g., rain or wind).

Table 3.1. Soil types, acreage, percent of watershed covered, and erodibility in the Galbraith Lake watershed, Marshall County, Indiana. Percent slope is given in parentheses behind applicable soil types. Soil types that are considered Highly Erodible Land (HEL) are indicated with an asterisk (*). Total HEL is listed at the bottom of the table. Erodibility due to factors of wind and water are given. Wind erosion on a scale of 1 = "extremely erodible" to 8 = "not subject to wind erosion". Susceptibility to sheet and rill erosion by water is indicated by erosion factor K, which ranges from 0.05 to 0.69, increasing in susceptibility. (Data compiled by the Marshall County Soil and Water Conservation District; Marshall County Soil Survey 1980)

Soil		acres	%	erodibility wind	erodibility water ("K")
AuA	Aubbeenaubbee sandy loam (0-2%)	8.0	4.4	3	0.24-0.32
BeA	Brems sand (0-2%)	9.6	16.3	1	0.17
Br	Brookston loam	9.6	5.3	6	0.28
ChB	Chelsea fine sand (2-6%)	22.0	12.1	2	0.17
CtA	Crosier loam (0-2%)	17.2	9.4	5	0.32
Gf	Gilford sandy loam	18.0	9.9	3	0.15-0.20
Ho	Houghton muck (drained)	5.6	3.1	3	---
MgB	Metea loamy fine sand (2-6%)	10.0	5.5	5	0.17-0.32
MgC	Metea loamy fine sand (6-12%)*	6.4	3.5	5	0.17-0.32
Ne	Newton loamy fine sand	8.0	4.4	2	0.17
OwA	Owosso sandy loam	14.0	7.7	3	0.28
PsA	Plainfield sand (0-2%)	17.2	9.4	1	0.17
PsC	Plainfield sand (3-10%)*	6.0	3.3	1	0.17
PsD	Plainfield sand (12-18%)*	4.8	2.6	1	0.17
Re	Rensselaer loam	5.6	3.1	5	0.28

Total watershed land acreage (excluding water surface) = 145 acres
Total Highly Erodible Land (HEL) = 17.2 acres (12 % of land acreage)

Descriptions of each soil type for description category are given below (Marshall County Soil and Water Conservation District; Marshall County Soil Survey 1980). Further information on species selection for woodland management, windbreaks, development of recreational facilities, habitat potential for wildlife, building sites, suitabilty for sanitary facilites, and physical, chemical, and engineering properties of individual soil types are available in the Marshall County Soil Survey.

AuA - Aubbeenaubbee sandy loam, 0 to 2 percent slopes. This soil is light colored, loamy in texture and on sloping uplands. It is deep and somewhat poorly drained with moderate permeability. It has high available water for plant growth and a low organic matter content.

BeA - Brems sand, 0 to 2 percent slopes. This soil is light colored, sandy in texture and on sloping uplands. It is deep and moderately well drained with rapid permeability. It has low available water for plant growth and a medium organic matter content.

Br - Brookston loam. This soil is dark colored, loamy in texture and on depressional uplands. It is deep and very poorly drained with moderate permeability. It has high available water for plant growth and a high organic matter content. It has compact till stratgin at a depth between 20 to 40 inches.

ChB - Chelsea fine sand, 2 to 6 percent slopes. This soil is dark colored, sandy in texture and on sloping uplands. It is deep and excessively drained with rapid permeability. IT has low available water for plant growth and a medium organic matter content.

CtA - Crosier loam, 0 to 2 percent slopes. This soil is light colored, loamy in texture and on sloping uplands. It is deep and somewhat poorly drained with slow permeability. It has high available water for plant growth and a medium organic matter content. It has compat till starting at a depth between 20 to 40 inches.

Gf - Gilford sandy loam. This soil is dark colored, loamy in texture and on depressional uplands. It is deep and very poorly drained with rapid permeability. It has moderate available water for plant growth and a high organic matter content.

Ho - Houghton muck, drained. This soil is dark colored, mucky in texture and on bottomlands. It is deep and very poorly drained with slow permeability. It has high available water for plant growth and a very high organic matter content.

MgB, MgC - Metea loamy fine sand, 2 to 6 percent slopes, 6 to 12 percent slopes. This soil is light colored, sandy in texture and on sloping uplands. It is deep and well drained with rapid permeability. It has moderate available water for plant growth and a medium organic matter content. It has compact till starting at a depth between 40 to 60 inches.

Ne - Newton loamy fine sand. This soil is dark colored, sandy in texture and on depressional uplands. It is deep and very poorlyl drained with rapid permeability. It has low available water for plant growth and a high organic matter content.

OwA - Owosso sandy loam, 0 to 2 percent slopes. This soil is light colored, loamy in texture and on sloping uplands. IT is deep and well drained with moderate permeability. IT has high available water for plant growth and a medium organic matter content. It has compact till starting at a depth between 20 to 40 inches.

PsA, PsC, PsD - Plainfield sand, 0 to 2 percent slopes, 3 to 10 percent slopes, 12 to 18 percent slopes. This soil is light colored, sandy in texture and on sloping uplands. IT is deep and excessively drained with rapid permeability. It has low available water for plant growth and a medium organic matter conttent.

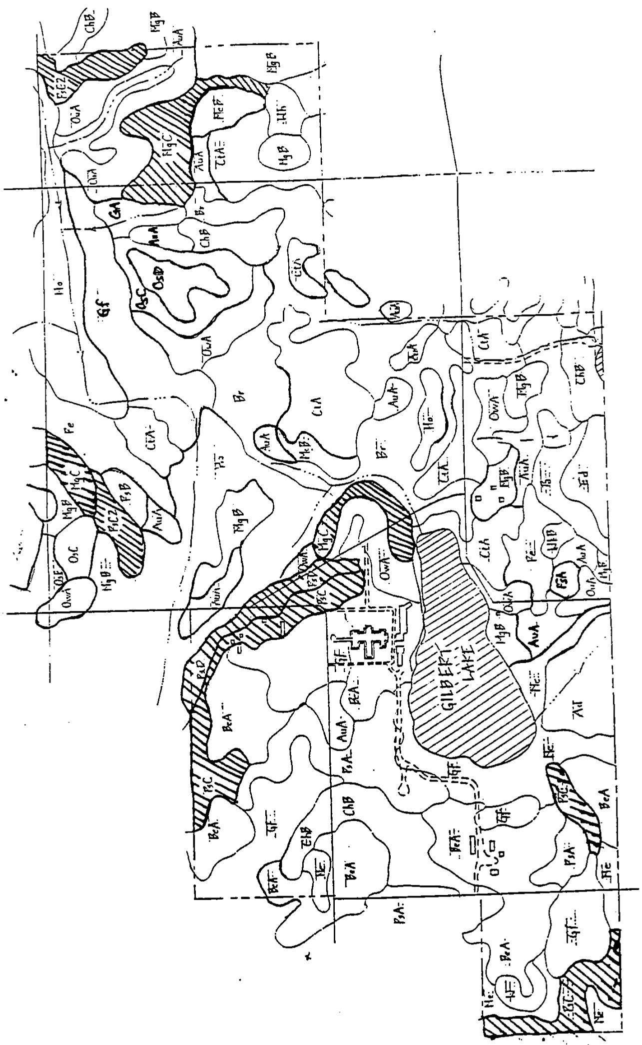
Re - Rensselaer loam. This soil is dark colored, loamy in texture and on depressional uplands. It is deep and very poorly drained with slow permeability. It has high available water for plant growth and a high organic matter content.

A relatively small portion of the Galbraith Lake watershed consists of highly erodible land (17.2 acres or 12 % of the land acreage). However, even limited soil erosion can be very costly for land management in rural and urban areas. Erosion diminishes productivity and increases runoff by resulting in reduction of infiltration, loss of basic plant nutrients, and degradation of soil structure. Conventional, plow-disk farming of corn in Indiana induces soil loss of 19 tons per acre per year (47 tons per ha). As a result, corn yields on severely eroded soil have been shown to decrease by up to 24 percent on Illinois and Indiana farms. Erosion rates of 6.9 tons per acre per year (17 tons/ha/yr) could cost farmers $79 per acre ($196/ha/yr) to replace the benefits of water and nutrients; for every $1 invested in soil conservation, an estimated $5.24 in replacement costs would be saved (Pimentel and others 1995).

One of the long-term costs of erosion is deteriorating water quality. About 60 percent of the tons of soil lost from U.S. cropland each year is deposited in streams and rivers (USDA, 1989). This sediment clogs waterways, accelerates aging in lakes, and reduces the storage capacity of reservoirs. Dredging to remove silt and restore function to these systems costs over $520 million annually in the U.S. (Clark 1985).

Highly erodible land in the Galbraith Lake watershed is located in patches (Figure 3.1). A long strip of HEL consisting of Metea loamy fine sand on 6 to 12 percent slopes borders the enter western side of the waterway entering the eastern end of the lake. A smaller patch of HEL exists on the southwest edge of the watershed. Stability of these soils is probably critical for maintaining lake water quality. A recent survey of tillage pracices across Indiana showed that only 20 percent of the cropland in the Marshall County portion of the Kankakee River basin was in conservation tillage (Hill et al. 1996). However, this percentage is an increase of 10 percent since 1990. Average erosion rates in 1996 were 2.4 tons per acre (lower than the state average of 3.0 tons per acre). Approximately 79% of the 1996 cropland was eroding below “T” or the tolerable level to

Figure 3.1. Map of soil types and Highly Erodible Land (HEL) in the region of the Galbraith Lake watershed. Areas of HEL are cross-hatched. Soil type abreviations are in the text and the Marshall County soil survey.



maintain agricultural productivity, which was just below the average for all counties in the river basin.

3.2 Current Land Use

The Galbraith Lake watershed is typical of most lake watersheds in Northern Indiana in that agriculture is the dominant land use in much of the watershed, but unusual in that areas immediately adjacent to the lake are dedicated to use by a single institution without cottage development. About 20 percent of the watershed consists of institutional property and about 40 percent is used for agriculture (Table 3.2).

Table 3.2. Land use in the Galbraith Lake watershed. Land use type is given by acreage and percent of total watershed covered. (Data compiled by the Marshall County Soil and Water Conservation District.)

Land use	acres	%
Water	37.0	20.3
Pasture	26.4	14.5
Cropland	35.0	19.2
Institutional	38.6	21.2
Woodland	17.2	9.5
Low density residential	10.0	5.5
Orchard and prairie grass	9.3	5.1
Organic garden	4.7	2.6
Wetlands	3.8	2.1

The Galbraith Lake watershed is owned by Ancilla, or Poor Handmaids of Jesus Christ. The current status of the land uses in the watershed is described below.

Pasture (26.4 acres)
Pasture fileds located along the south end of the lake and east of Union Road have remained in pasture since 1981. Water access for cattle was limited to one area near the lake outlet in 1993. This measure has reduced shoreline erosion and possibly nutrient input from cow manure.

Cropland (35.0 acres)
A review of cropping history, from 1981 to present, at the Farm Service Agency indicates a usual rotation of corn and beans. Occasionally, wheat was used. Only one cropland field (9.5 acres) is considered HEL. A long term alfalfa rotation is utilized on this field.

Institutional (38.6 acres)
All buildings, paved lots, roadways, and mowed grassy areas that make up Ancilla Convent, Ancilla College, Lindenwood, the Maria Center, and the Kasper Home were included in this category.

Organic garden (4.7 acres)
The organic garden area covers 4.7 acres on the west end of the lake and was used as a pasture prior to 1989. The garden is a cooperative effort with many people from surrounding communities and Earthworks at Ancilla.

Woodland (17.2 acres)
Both deciduous and pine trees were included in the woodland category. The remaining 7.7 acres of HEL soil is located near Union and 9 B Road in a wooded area.

Low density residential (10.0 acres)
Includes residential and farmstead areas not included in the "institutional" area.

Orchard and prairie grass (9.3 acres)
The orchard has a very limited number of trees remaining, warm season grasses and wildflowers have been planted in part of the area.

Wetlands (3.8 acres)
Small wetland areas, totally 3.8 acres are located on the east and west ends of the lake.

As indicated above, nearly all acreage considered to be HEL is currently protected by either a cover crop or forest.

Wildlife habitat and locations that could provide sources of species for restoring plant and wildlife communities are relatively abundant in the region around the Galbraith Lake watershed. A number of endangered, threatened and rare species have been documented from Marshall County (Table 3.3). The region immediately around Galbraith Lake supports several unusual species and habitat types, associated with wetland, prairie, and forested areas (Table 3.4). Like much of Northern Indiana, most of the forested areas around the Galbraith Lake watershed are fragmented into several small scattered tracts with the exception of a fairly large continuous forested area on the southwest edge of the watershed (Figure 3.2). A fairly extensive wetland area borders the entire length of the southwest side of the outlet stream from Galbraith Lake to South Union Road.

Figure 3.2. Map of forested tracts in the region of the Galbraith Lake watershed (redrawn from the 1972 USGS topographic map). The heavy line indicates the approximate watershed boundary. Forested areas are indicated by cross-hatching.

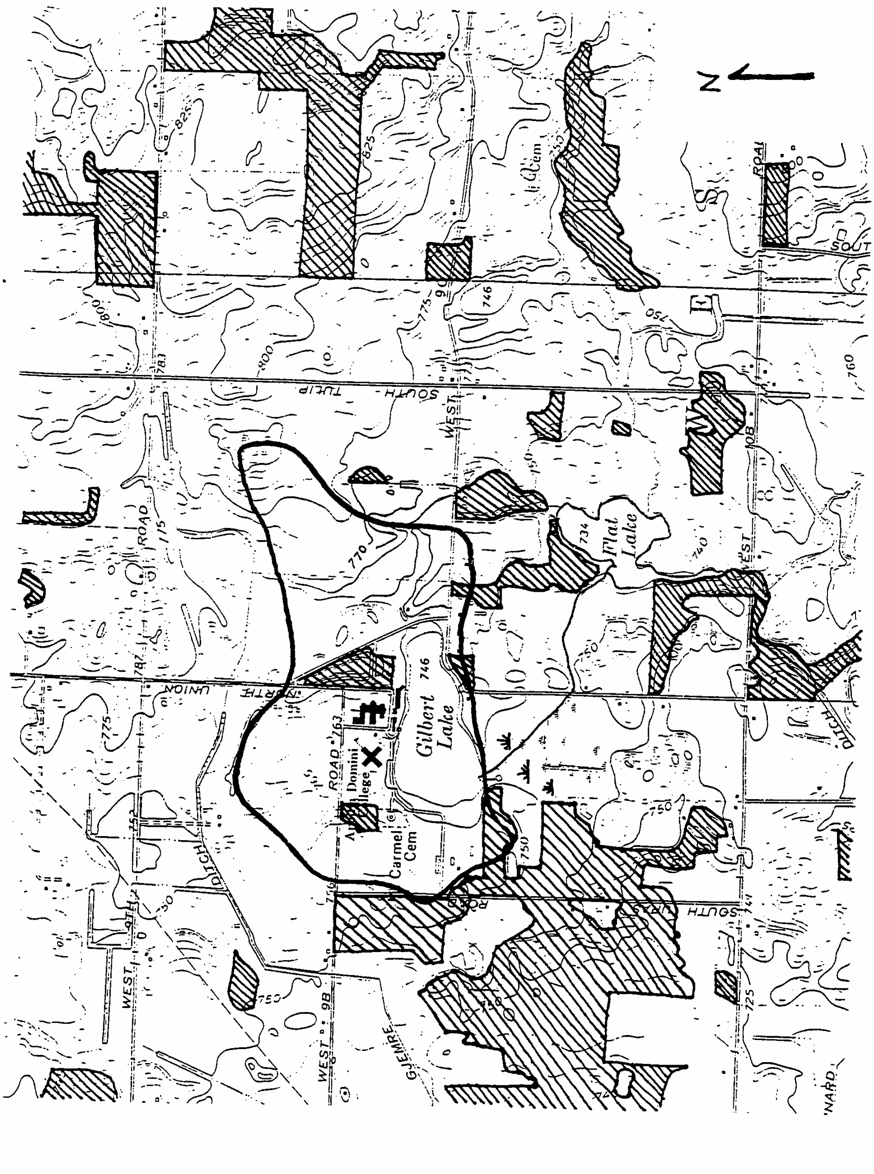


Table 3.3. Endangered, threatened and rare species that have been documented from Marshall County. (State listed: SX=extirpated, SE=endangered, St=threatened, SR=rare, SSC=special concern, WL=watch list, SG=significant; Federally listed: LE=endandered; Indiana Heritage Trust Database, January 2, 1997).

Common name	Species name	Status
Mammal		
Franklin's ground squirrel	*Spermophilus franklinii*	ST
American badger	*Taxidea taxus*	ST
Sharp-shinned hawk	*Accipiter striatus*	SSC
Great blue heron	*Ardea herodias*	SSC
American bittern	*Botaurus lentiginosus*	SE
Brown creeper	*Certhia americana*	WL
Marsh wren	*Cistothorus paustris*	SE
Cerulean warbler	*Dendroica cerulea*	SSC
Least bittern	*Ixobrychus exilis*	SE
King rail	*Rallus elegans*	SE
Virginia rail	*Rallus limicola*	SSC
Hooded warbler	*Wilsonia citrina*	SSC
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*	ST
Reptile		
Spotted turtle	*Clemmys guttata*	ST
Kirtland's snake	*Clonophis kirtlandii*	ST
Blanding's turtle	*Emydoidea blandingii*	SE
Eastern Massasauga	*Sistrurus catenatus catenatus*	ST
Ornate box turtle	*Terrapene ornata*	SSC
Butler's garter snake	*Thamnophis butleri*	ST
Fish		
Cisco	*Coregonus artedi*	SSC
Eastern sand darter	*Etheostoma pellucidum*	SSC
Ohio lamprey	*Ichthyomyzon bdellium*	WL
Mussel		
Slippershell mussel	*Alasmidonta viridis*	WL
Wavy-rayed lampmussel	*Lampsilis fasciola*	SSC
Black sandshell	*Ligumia recta*	WL
Clubshell	*Pleurobema clava*	SE, LE
Kidneyshell	*Ptychobranchus fasciolaris*	SSC
Gastropod (snails)		
Pointed campeloma	*Campeloma decisum*	SSC
Swamp lymnaea	*Lymnaea stagnalis*	SSC

Table 3.3. Endangered, threatened and rare species, cont.

Vascular plant		
Lake cress	*Armoracia aquatica*	SE
Rushlike aster	*Aster junciformis*	SR
Long-bract green orchis	*Coeloglossum viride var virescens*	ST
Small white lady's slipper	*Cypripedium candidum*	SR
Horse-tail spikerush	*Eleocharis equisetoides*	SE
American manna-grass	*Glyceria grandis*	SX
Great St. John's wort	*Hypericum pyramidatum*	SE
Large roundleaf orchid	*Platanthera orbiculata*	SX
Grove meadow grass	*Poa alsodes*	SR
Straight-leaf pondweed	*Potamogeton strictifolius*	SE
Hairy valerian	*Valeriana edulis*	SE
Horned pondweed	*Zannichellia palustris*	SE
High quality community		
Mesic prairie		SG
Marl beach		SG
Acid bog		SG
Fen		SG
Muck flat		SG

Table 3.4. Endangered, threatened and rare species that have been documented from the region immediately around the Galbraith Lake watershed (Donaldson Quadrangle; Indiana Heritage Trust Database, January 2, 1997).

Species or community	Scientific name or type	Status	Date
State owned habitat			
Menominee Wetland Conservation Area - IDNR Division of Fish and Wildlife			
High quality wetland	Muck flat	SG	1985
Privately owned habitat			
High quality wetland	Fen	SG	1985
High quality forest	Sand flatwoods	SG	1985
High quality prairie	Mesic prairie	SG	1983
Species			
American badger (mammal)	Taxidea taxus	ST	1987
Dusted skipper (insect)	Atrytonopsis hianna	ST	1990
Great blue heron (bird)	Ardea herodias	SSC	1993

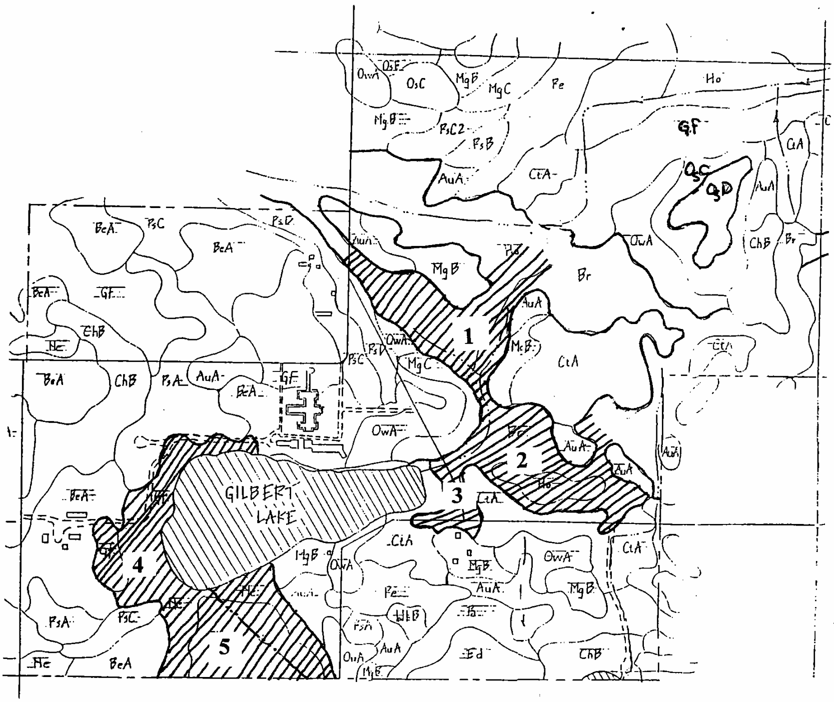
Wetland restoration or enhancement requires an appropriate combination of soil types, topography, and coordination with existing or potential land uses. Soil types in the Galbraith Lake watershed that are amenable to wetland restoration are: Adrian, Brookston, Gilford, Houghton, Newton, and Rensselaer. Areas over wetland soils that drain immediately into waterways include: 1) a broad area between the upper branches of the unnamed east inlet stream; 2) an area extending to the southeast from the bend of the unnamed east inlet stream; 3) all areas immediately adjacent to and a strip to the south of the lower reach of the unnamed east inlet stream; 4) areas bordering the western half of the lake, extending from the west edge of campus on the south side of the road around the northwest corner of the lake, bordering the east edge of the organic garden to a location on the south side of the lake half way from the outlet to South Union Road; and 5) an extensive area surrounding the outlet stream (Figure 3.3).

Areas bordering the lake previously supported wetland plant communities (T. Fraiser, Groundskeeper, Ancilla Domini Convent and College, pers. comm., February 15, 1995). The northeast edge of the lake retains a very small wetland and reportedly supported cattail in the past. The southwest corner previously consisted of a more extensive wooded swamp, but currently serves as pasture, as a sewage lagoon site, and for other agricultural use. Marsh mallow and button bush also used to occur along the western edge of the lake. Purple loose strife has recently invaded the southern shore of the lake near the public access site.

Water enters and leaves the lake from a variety of natural and artificial sources. A well-defined intermittent stream channel enters the east end of the lake. A wetland area drains through a poorly defined channel on the west end of the lake. Seven stormwater outfalls from the institution drain into the north side of the lake. Finally, a small sewage treatment plant that services the institution used to discharge directly to the lake. The treated wastewater currently discharges into a 0.25 acre lagoon that acts as a finishing pond before emptying into the lake. The lagoon is sealed with clay (bentonite). Permit limits include: 10 mg/l BOD; 15 mg/l TSS (total suspended solids); pH of 7.5-7.7; and capacity of 15,000-20,000 gallons/day. Iron filters at the sewage treatment plant are backwashed into the lake with 20,000 gallons of water once a week with 4 pounds of potassium permanganate ($KMnO_4$) in 20,000 gallons once per month. Extended aeration with settling tanks is used with excess sludge pumped to another plant. No heavy metals have been detected in the sludge (T. Fraiser, Groundskeeper, Ancilla Domini Convent and College, pers. comm., February 15, 1995). A channelized outlet drains the lake to Flat (Mud) Lake through a paritially tiled wetland area.

Galbraith Lake has supported a fluctuating level of recreational use over the past several decades. Approximately 30-40 years ago, the lake was regularly fished by local residents, including ice fishing (T. Fraiser, Groundskeeper, Ancilla Domini Convent and College, pers. comm., February 15, 1995). Declines in water quality and simultaneous declines in sport fish in the lake have resulted in a lower level of use for fishing and swimming. The convent owns a pontoon boat that is occassionally used for pleasure boating on the lake.

Figure 3.3. Map of soils with potential for wetland habitat development. Areas with amenable soils are cross-hatched. Numbers 1 to 5 indicate areas discussed in the text of the report.



4.0 LAKE ASSESSMENT

Lakes are complex ecosystems in which physical, chemical, and biological characteristics function interdependently. Large scale factors, such as climate and geology, set the stage within which individual lake characteristics develop. Lakes in northern Indiana tend to be highly productive, hardwater lakes surrounded by forested wetlands. These lakes age naturally over hundreds of years. Some physical and chemical factors, like temperature and light, determine the type of organisms that can survive in the system. Other physical and chemical factors, like dissolved oxygen, may result from biological activity. Physical, chemical, and biological characteristics of Galbraith Lake are described below.

4.1 STRATIFICATION

Galbraith Lake exhibited thermal and chemical stratification during late summer sampling on August 16, 1995 With the exception of very shallow lakes, most lakes in northern Indiana will stratify so that warmer water remains near the surface of the lake and water at the bottom is colder. Due to the difference in temperature and density, warmer water from the surface "floats" on top and does not mix with denser, colder water at the bottom. As a result, chemical characteristics of surface and bottom water may differ dramatically, such that few organisms can live in deeper parts of the lake in summer.

4.1.1 Oxygen and temperature

Oxygen saturation and pH levels at the surface were relatively low in Galbraith Lake during 1995 (Table 4.1; Figure 4.1), suggesting that algal and rooted plant populations were not overly abundant. Levels of oxygen were supersaturated from 130% at the surface to 100% at a depth of about six feet and dropped below four mg/l at a depth of 10.5 feet. Supersaturation of oxygen indicates high productivity of algal and other aquatic plants during the day and may reach 150% or more in surface waters of highly eutrophic lakes. At night the reverse process may take place, causing an equivalent amount of oxygen to be removed from the water by respiring plants. This activity can lead to fish kills in highly productive lakes.

Figure 4.1. Dissolved oxygen, oxygen saturation, and temperature in Galbraith Lake on August 16, 1995.

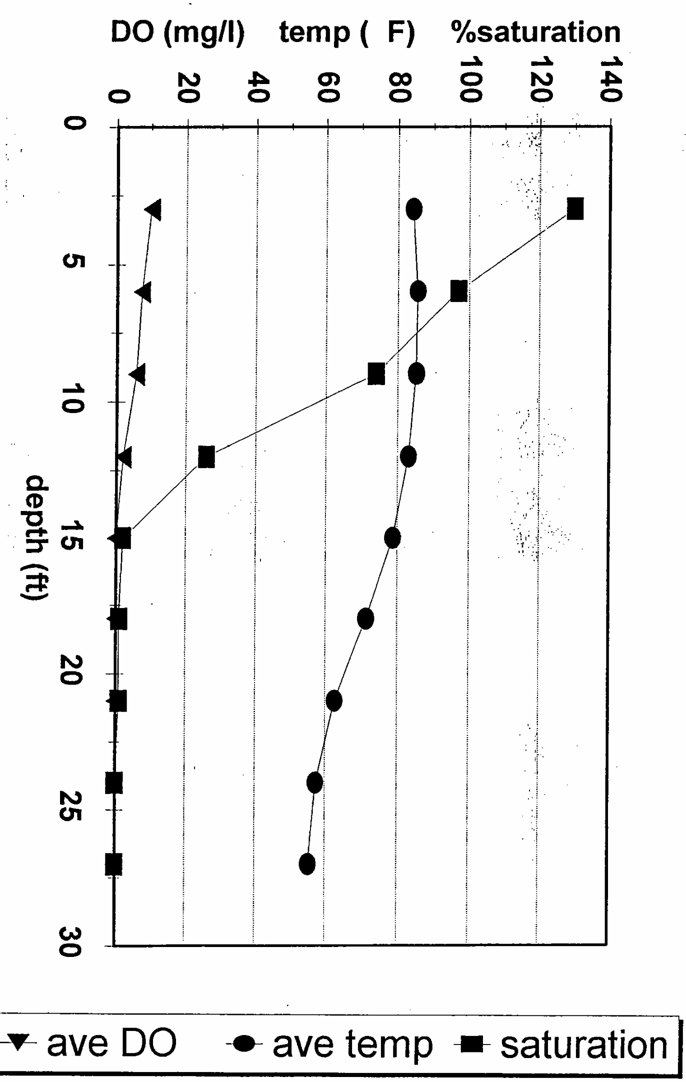


Table 4.1. Stratification of Galbraith Lake, Marshall County, Indiana in late summer, August 16, 1995, at the deepest part of the lake. Parameters given are depth (ft), average of two readings for dissolved oxygen (mg/l) and temperature (^{O}F), and percent saturation for dissolved oxygen at depths of every three feet from surface to bottom.

depth (ft)	ave DO (mg/l)	ave temp (^{O}F)	saturation %
3	10	84.3	130
6	7.3	85.6	97
9	5.65	85.3	74
12	2.05	83.1	26
15	0.125	78.9	2
18	0.075	71.4	1
21	0.05	62.7	1
24	0.025	57.4	0
27	0.005	55.3	0

In general, oxygen levels below four mg/l are too low to support most aquatic organisms. Low levels of oxygen in Galbraith Lake created an uninhabitable condition in waters deeper than seven ft in 1995, which extended to a maximum of 13 ft in 1990 and 1991 (Figure 4.2). Unfortunately, the temperature of inhabitable areas can also get fairly high, not dropping below 85^{O}F in 1995, but generally ranging between 70 and 85°F (Figure 4.3). High temperatures can limit growth rates of fish and other aquatic organisms, because higher respiration rates may result in wasted energy that could have produced growth. In addition, high temperatures can exacerbate effects of toxic chemicals and increase growth of undesirable algae and bacteria. The highest temperature recommended for toxicity studies on fish is 80^{O}F (Rand and Petrocelli, 1985). Other warm years were 1970 and 1991. Coolest summer surface temperatures were in 1976 and 1979. Although most data was collected in mid to late summer, some difference in recorded temperature may be a function of the time of year that readings were taken rather than reflecting conditions peculiar to that year.

4.1.2 pH and alkalinity

Many chemical reactions are associated with changes in pH. High rates of photosynthesis at the surface of lakes can create pH levels above 10 in highly eutrophic lakes. Hardwater lakes rarely have a pH below 7.0. Low pH levels at the bottom of stratified lakes is a result of acidic conditions created by respiration and decay of plants and animals. Late summer pH in Galbraith Lake during 1995 was 8.8 at the surface and 7.1 at the bottom. These readings were fairly low readings compared to other years at the surface and average to low for the bottom (Figure 4.4). The pH of Galbraith Lake ranged from 7.0 at the bottom in in four years between 1973 and 1995 to 10.0 at the surface and

Figure 4.2. Dissolved oxygen profiles over the deepest part of Galbraith Lake during eight years of sampling from 1970 to 1995.

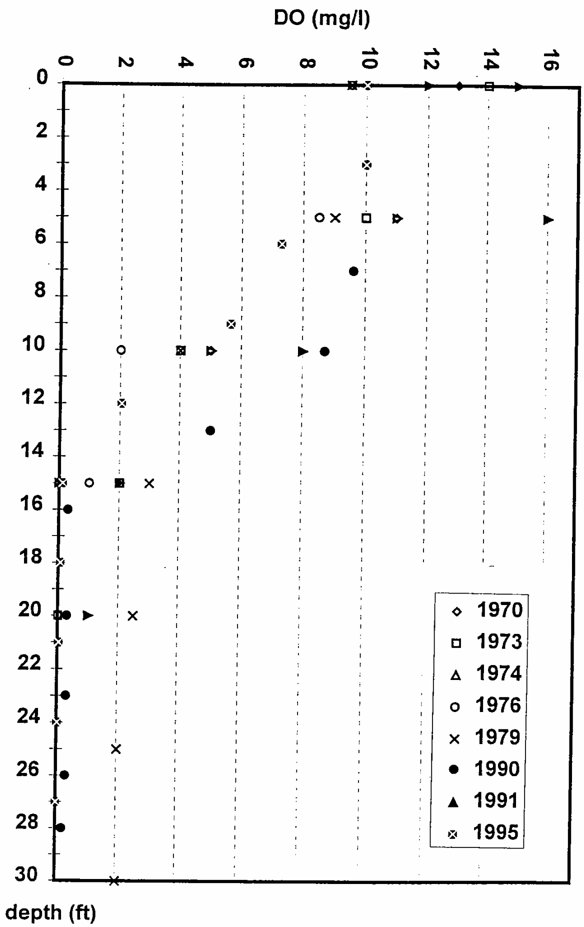


Figure 4.3. Temperature profiles over the deepest part of Galbraith Lake during eight years of sampling from 1970 to 1995.

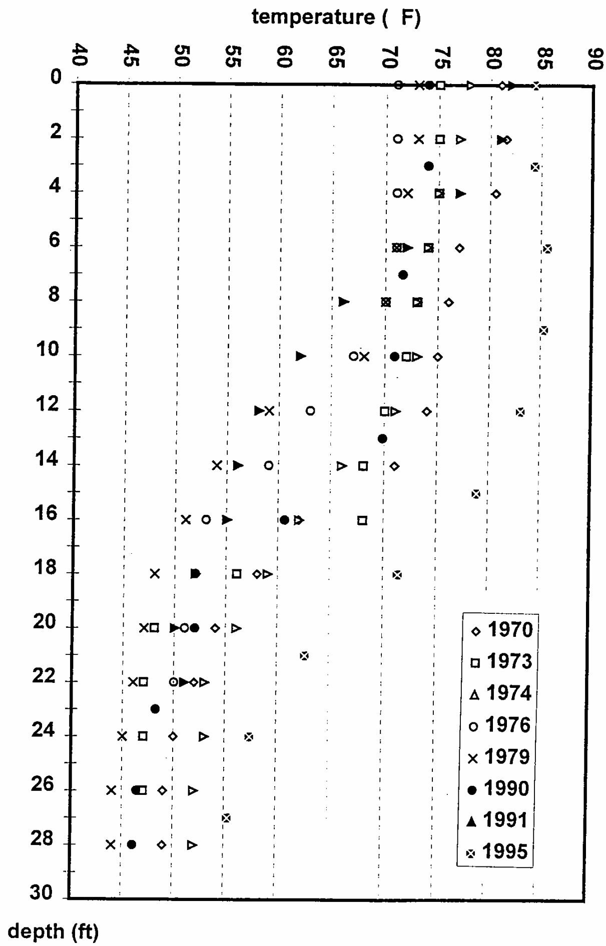
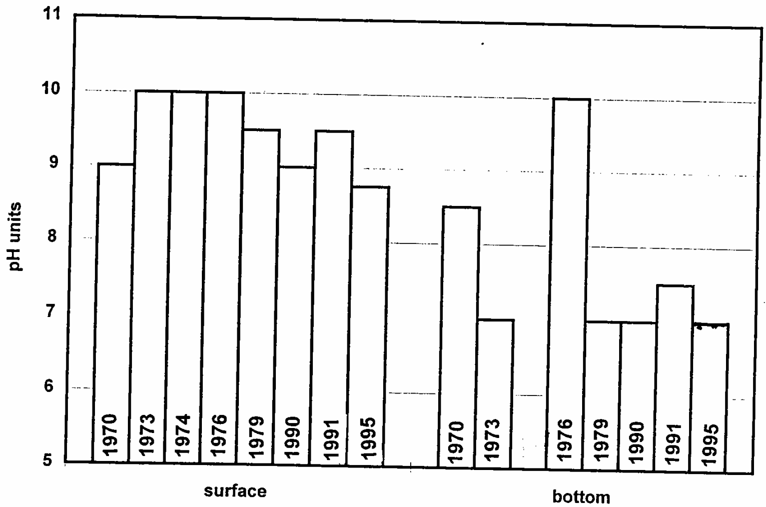


Figure 4.4. Level of pH from surface and deep waters in Galbraith Lake during eight years of sampling from 1970 to 1995.



bottom in 1976 and at the surface in 1973 and 1974. High pH levels at the surface from 1973 to 1976 and throughout the lake in 1976 may have been a result of increasingly high algal productivity, indicated by other measurements in those years as well. In the fall of 1995, pH at the surface was 8.1. Decreases in surface pH reading during the fall can be an indication of decreased plant activity or mixing of surface and deeper water during turnover.

Phosphorus and some toxins, such as heavy metals, are released into the water when pH levels drop and water acidify. Negative effects of these compounds are generally lessened by alkalinity above 50 mg/l in hardwater lakes. Seasonal and daily shifts in pH are generally less dramatic in northern Indiana lakes, because carbonates from erosion of limestone and other minerals from the soil can buffer pH changes. Other chemicals, such as borates, phosphates, silicates, and other bases also affect alkalinity. In polluted lakes, organic anions may become a part of total alkalinity.

Daytime photosynthesis of plants removes carbon dioxide (CO2) from the water and causes calcium carbonate (CaCO3) to precipitate, lowering total alkalinity. This effect is exacerbated in warmer water. The precipitate of calcium carbonate falls to the bottom of the lake, where it is reabsorbed into the water and increases the alkalinity in deeper waters. Alkalinity becomes more even throughout the lake at turnover and through the winter.

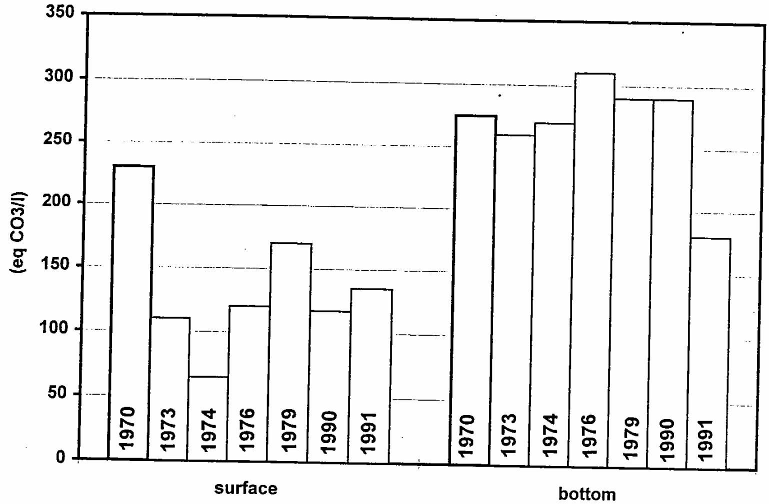
Total alkalinity in Galbraith Lake may reflect changes in pollution and plant productivity over the past 20 years. Alkalinity ranged from a low of 68 mg/l at the surface in 1974 to a high of 306 mg/l at the bottom in 1976 (Figure 4.5). High alkalinity at the bottom of Galbraith Lake may be an artifact of past pollution, especially input of phosphates from detergents. In addition, high plant productivity was indicated in years when surface and bottom alkalinity were very different, especially in 1974 and 1976. Surface and bottom alkalinity were both fairly high in 1970. Both values were relatively low in 1991, possibly indicating a decrease in effects of pollution and lower plant and algae productivity.

4.2 LIGHT AND PLANKTON

Phytoplankton are microscopic plants function as the primary producers of food and oxygen in lake ecosystems. As with other plants, phytoplankton require light and nutrients to thrive. Transparency and light penetration in the water regulate the type and location of phytoplankton in the lake. In turn, phytoplankton can control light penetration and dissolved oxygen levels in eutrophic lakes.

Only a few species of adult fish in temperate lakes feed directly on phytoplankton. Most of the energy produced by phytoplankton is transferred through the food web via consumption of phytoplankton by small zooplankton (microscopic animals), which are eaten by larger zooplankton or young fish. Populations of phytoplankton, zooplankton, and young fish are intimately connected, depending on population size and feeding rate of

Figure 4.5. Alkalinity from surface and deep waters in Galbraith Lake during seven years of sampling from 1970 to 1991.



predators and prey in the food web. Expansion of one group may cause a corresponding increase in its predators and decrease in prey.

4.2.1 Light and water clarity

Water clarity in Galbraith Lake appears to have shown consistent and significant improvement over the past decade. Secchi depths have improved by over 400 percent in ten years from an annual average or individual summer reaading of only one foot in 1976 (IDNR, 1976) and 1986 (IDEM, 1988-89) to nearly four feet in 1990 and 1995 (Figure 4.6). The majority of Indiana lakes have a Secchi depth greater than 5 ft (IDEM, 1986). However, shallow lakes tend to have lower water clarity. The average for Marshall County lakes of a similar size and depth as Galbraith Lake (16-40 acres) was 5.8 ft. Clarity in Galbraith Lake will have to increase by another 25 percent to achieve acceptable water clarity for Indiana lakes (Secchi reading over 5 ft).

Water clarity may be affected by suspended silt, growth of microscopic algae or dissolved substances that color the water. Seasonal changes in water clarity from April through October in 1990 and 1991 demonstrate a trend of reduced clarity in the spring and possibly late fall with a generally consistent increasing or stable clarity during the summer and early fall months (Figure 4.7). This pattern suggests that the most significant factor contributing to reduced water clarity may be due to eithoer or both of the following processes: 1) sedimentation in runoff after spring and fall rains; or 2) an increase in algal population in response to mixing of nutrients from the lake bed at turnover. This evidence is further corroborated with the algae data given below that showed no dominance of bluegreen algae in the summer sample, but an increase in bluegreens in the fall sample in 1995. Secchi depth also decreased in 1995 from the summer reading of 4.1 ft to a fall reading of 3.8 ft.

Plants require light for growth. Penetration of light is directly related to water clarity. Competition between unwanted bluegreen algae and beneficial plants is mediated by the amount of light available for rooted plant production. In general, rooted aquatic plants can grow to a depth that is three times the Secchi measurement, while bluegreen algae are more tolerant of low light levels. Therefore, submerged aquatic plants could not grow well in Galbraith Lake at depths greater than three to six feet through the 1970s and 1980s. Recent improvements in water quality may permit rooted plant growth to depths of 12 ft or more. As plant growth extends into deeper waters, the amount of oxygen and habitat available for aquatic animals may increase as well.

4.2.2 Phytoplankton

Phosphorus generally acts as the limiting nutrient in fresh water ecosystems. As discussed in detail below, bottom sediments in Galbraith Lake likely contain a great deal of phosphorus due to past inputs from septic systems, livestock, and fertilizers. Recycling and availability of phosphorus increases in the water column towards early fall, as the lake begins to turn over and unlock high levels of phosphorus from the

Figure 4.6. Average or individual annual readings for Secchi depth in Galbraith Lake during eight years of sampling from 1970 to 1995. Average readings are indicated by a number denoting the number of readings for that year.

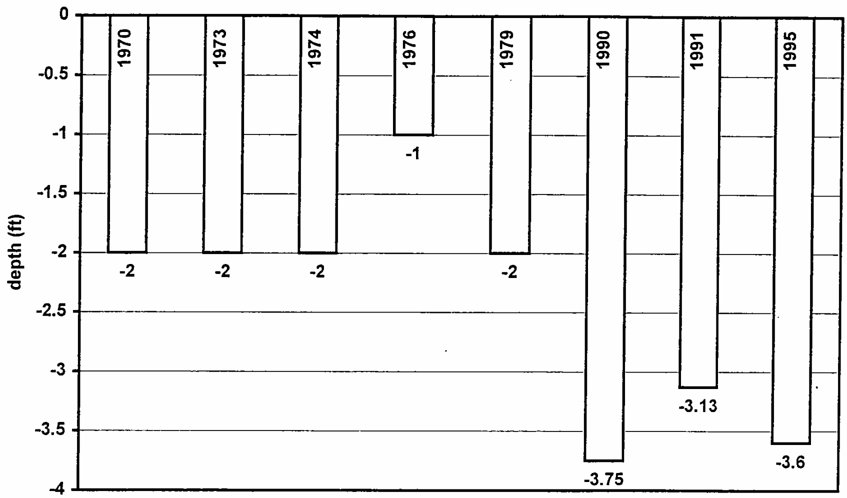
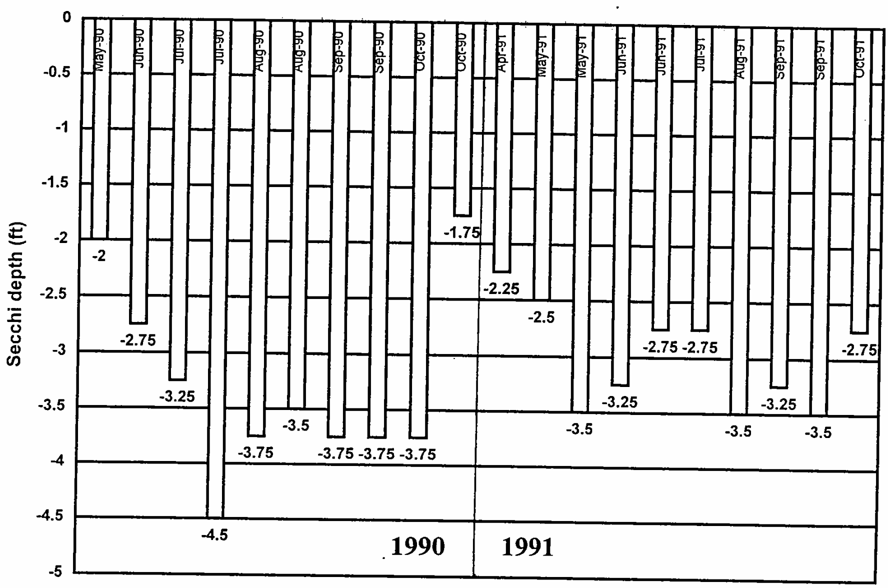


Figure 4.7. Seasonal readings for Secchi depth in Galbraith Lake during 1990 and 1991 (IDEM 1992).



sediment at the bottom of the lake. As nutrients become more available, algal blooms occur.

Phytoplankton generally increase with warming temperatures and longer daylight hours into late June and early July, then begin to decrease as herbivorous zooplankton population begin increasing and feeding on the microscopic plants. Collections from Galbraith Lake showed a dramatic increase in phytoplankton density in September, as compared to August. This trend may result from a combination of food availability for phytoplankton growth and grazing pressure by zooplankton.

Both abundance and species diversity of phyplankton, or microscopic plants, increased between the late summer and fall samples (Table 4.2). The dinoflagellate *Ceratium* and green algae *Eudorina* disappeared in fall, along with reductions in the bluegreen *Coelospharium*. Dinoflagellates, such as *Ceratium*, grow well under intense light conditions, but are poor competitors for food resources compared to most species of green and bluegreen algae. Diatoms are particularly important as a food resource for newly hatched fish fry in the spring. As grazing pressure of zooplankton and competition with bluegreen algae increase, most species of diatoms disappear by the end of July (Lund, 1964; Heron, 1961). No spring or early summer collections were taken in this study. However, the diatom *Fragillaria* commonly reproduces in fall and was captured in the September sample.

Table 4.2. Phytoplankton collected from Galbraith Lake, Marshall County, Indiana, in late summer (August 16) and fall (September 22), 1995. The upper zone represents a composite of three plankton tows from a depth of five feet. The lower zone represents a composite of three plankton tows from a depth of 11 feet to the surface, minus the number of organisms found in the tow from the upper zone. The bottom of the lower zone constituted the one percent light level, based on L1%=2.5*Sechi depth.

species	August 16 upper zone	August 16 lower zone	September 22 upper zone
Bluegreen algae (Cyanophyta)			
Coelospharium	214	2138	855
Anabaena		641	641
Aphanizomenon			1283
Mycrocystis	214	855	26800
Oscillatoria			285
Green algae (Chlorophyta)			
Ulothrix		428	356
Volvox		214	143
Eudorina	641	1924	
Coelasterium			71
Kirchneriella			71
Closterium			1782
Protococcus			1711
Treubaria			71
Pediastrum			143
Richterella			71
Stigeoclonium			71
Dichtyosphaerum			71
Cladophora			71
Euglenophyta			
Trachelomonas			214
Diatoms (Chrysophyta)			
Cymbella			71
Fragilaria			214
Other Chrysophyta (not diatoms)			
Dinobryon		428	784
Mallamonas		428	71
Synedra			71
Dinoflagellates (Pyrrophyta)			
Ceratium	214	641	
Total phytoplankton/L	**1283**	**7697**	**36064**
Total bluegreen	**428**	**3634**	**30007**
Percent bluegreen	**33%**	**47%**	**83%**

Populations of the bluegreen algae may increase dramatically in late summer and fall, causing beneficial algae species and rooted plants to become less abundant. Several species of bluegreen algae, including *Mycrocystis* and *Anabaena*, and the diatom *Fragillaria* are commonly occur in hardwater lakes with high alkalinity, like Galbraith Lake. However, an overabundance of bluegreen algae can create a nuisance in lakes used by humans. These species cause noxious blooms and high daytime pH levels in eutrophic lakes. Bluegreen algae may form dense mats across the surface that are unsightly, impede recreation, and shade out rooted plants. In addition, only a few aquatic animals eat bluegreen algae. Several bluegreen species found in Galbraith Lake can produce strains that cause unacceptable taste and odor in drinking water and can cause poisoning deaths of fish, cattle, and hogs (Lampert, 1987). Consequently, the only naturally occurring control of bluegreen algae is competition between bluegreen species and cold temperatures or eventual consumption of critical nutrients. Decomposition of large dying populations can consume oxygen and result in fish kills.

Patterns of algal growth in Galbraith Lake match those predicted from studies in other lakes, with bluegreens increasing dramatically in fall samples. Bluegreen algae have a sporelike resting stage that overwinters in the sediments. During the spring, most bluegreen algae multiply slowly in colder water, but "hatch" from the sediments and rapidly reproduce in warmer water of summer through early fall.

A complex interaction of competing species with different capabilities controls the population dynamics of bluegreen algae. A few bluegreen species, including *Aphanizomenon* and *Anabaena*, are capable of using nitrogen gas from the atmosphere and so have an added advantage over green algae and other species of bluegreens, such as *Mycrocystis* and *Oscillatoria*, which must take nitrogen directly from the water (Horne, 1975). For this reason, *Aphanizomenon* populations may grow rapidly in spring and early summer and die out in mid- to late summer as necessary iron resources are depleted. By mid-summer, *Anabaena* starts to grow because death of floating *Aphanizomenon* allows more light to reach the less buoyant *Anabaena*. *Mycrocystis* peak from late August through October, as ammonia becomes available from decomposition of dying plants and animals in deoxygenated sediments. Release of ammonia and phosphorus from the sediments during alternating calm and windy periods during late summer or at fall turnover can produce a significant bloom of *Mycrocystis*. Ammonia from other sources, such as manure application or inadequate sewage treatment, can also contribute to blooms of *Mycrocystis*.

Daily migrations from deeper, darker water to sunlit surface waters occur for some bluegreen algae, including *Mycrocystis*, *Anabaena*, and *Aphanizomenon*. These species accumulate gas in their tissues, rising to the surface at night and sinking during mid-morning. This phenomenon may also explain why bluegreen algae was more common in deeper samples during mid-afternoon in August and were more common at the surface in the September sample, which was retrieved in the morning.

4.2.3 Zooplankton

Zooplankton play a critical role in lake ecosystems by transferring productivity from primary producers (plants) to other organisms in the food web. Microscopic animals are particularly important in the diet of young fish, including bass, bluegill, and other sportfish. In Galbraith Lake, zooplankton were found at nearly twice the density in the fall compared to late summer samples (Table 4.3). This pattern is common in temperate lakes. Zooplankton populations commonly increase from late June to mid-July, then decrease dramatically until early September, when they begin to increase again and may nearly reach spring levels (Wright, 1965). Several phenomena may explain these patterns.

Table 4.3. Zooplankton collected from Galbraith Lake, Marshall County, Indiana, in late summer (August 16) and fall (September 22), 1995. The upper zone represents a composite of three plankton tows from a depth of five feet. The lower zone represents a composite of three plankton tows from a depth of 11 feet to the surface, minus the number of organisms found in the tow from the upper zone. The bottom of the lower zone constituted the one percent light level, based on L1%=2.5*Sechi depth.

species	August 16 upper zone	August 16 lower zone	September 22 upper zone
Rotifera			
Asplanchna			4704
Testudinella			1497
Keratella	18	3849	
Trichocerca	4	855	
Copepoda			
Cyclops			1283
Total zooplankton	**22**	**4704**	**7484**
Percent of total plankton	**1.7%**	**38%**	**17%**

Zooplankton generally rise to the surface at night to feed on phytoplankton, but remain at deeper, darker levels during the day to avoid predators. The late summer sample was collected from offshore waters in Galbraith Lake during early afternoon when zooplankton were more likely to be found deeper in the water, whereas the fall sample was taken in nearshore waters from the end of the boat dock at mid-morning and may have caught zooplankton still feeding near the surface. These migrations tend to be most strong in clear lakes with high predation pressure from planktivorous adult shad and minnows and young fish of many species (Carpenter et al., 1987). Apparent zooplankton responses to predation and water clarity possibly reflecting improved conditions in Galbraith Lake.

On the other hand, zooplankton avoid warm water during the day to reduce the cost of high respiration rates. Zooplankton and fish commonly spend most of the day in deeper, cooler water and move into the upper, warmer water at night or for brief forays during the day. Unusually warm temperatures at the surface of Galbraith Lake in late summer may have driven zooplankton to deeper water during the day. However, deeper cooler water in the summer contained very little, if any, oxygen and may not provide acceptable temperature refuge for zooplankton or fish.

Populations of different species of zooplankton peak at different times in the year due to food availability and competition. In Galbraith Lake, species composition of the rotifer community shifted from *Keratella* and *Trichocerca* in late summer to *Asplanchna* and *Testudinella* in the fall. Two main peaks in abundance of the large predatory rotifer *Asplanchna* usually occur in early spring and autumn, according to research conducted on other lakes (Dumont, 1972). Smaller rotifers feed on phytoplankton and increase with enhanced plant growth through late summer. Because *Asplanchna* feeds mostly on *Keratella* and other small rotifers, as well as some phytoplankton, as *Asplanchna* populations increase, populations of *Keratella* and other small rotifers decrease towards fall. In late fall, lower light and temperature levels inhibit plant growth and animal feeding rates decrease. As a result, the number of phytoplankton found in a liter of water may be nearly equal to or even less than the number of zooplankton during the winter.

4.3 SHORELINE AND AQUATIC PLANTS

Former wetland areas around Galbraith Lake have been altered by agricultural land use. A low-lying marshy area still exists along the western shore, where an intermittent stream enters the lake. This wetland area acts as a buffer between the lake and a 2.7 acre organic garden. Marsh mallow and buttonbush are not as abundant as they were previously (T. Fraiser, Groundskeeper, Ancilla Domini Convent and College, pers. comm., February 15, 1995). In the past, the northeast side of the lake was low, wet, and dominated by cattail. The southwest corner of the section was wooded swamp and has been converted to agricultural use.

Native plant species found around Galbraith Lake are all relatively common in this region of Indiana. Although the species need not be protected for their rarity, these rooted plants on shore and in shallow lake areas play a vital role in stabilizing the shoreline and providing habitat to semi-aquatic and terrestrial animals around the lake. Emergent plants on the north shore seem to be maintaining the banks fairly well. The area in the southwestern corner of the lake around the outlet was relatively devoid of aquatic and onshore vegetation, likely due to grazing of cattle onshore and into the lake. At least 12 species of trees (including three exotic species), 44 species of shore plants (14 exotics), 10 species of emergent plants, one species of floating plant, and one species of submergent plant were identified during July, 1995 (Table 4.4). Purple loosestrife has been common in areas around the public access and may be contributing to turbidity in the lake by carrying soil with its roots as it falls into the water. This species is a very serious competitor with native species of shoreline plants, provides little to no habitat benefits, and should be pulled by hand or treated chemically to limit its spread.

Table 4.4. Plant species found in and around Galbraith Lake, Marshall County, Indiana, in July, 1995. Invasive exotic plants are listed first and indicated with an asterisk (*).

Common Name	**Latin name**
Trees	
Bald cypress*	*Taxodium distichum*
Chinese elm*	*Ulmus parviflora*
European alder*	*Alnus glutinosa*
American elm	*Ulmus americana*
Alternate leaved dogwood	*Cornus alternifolia*
Black willow	*Salix nigra*
Box elder	*Acer negundo*
Eastern cottonwood	*Populus deltoides*
Green ash	*Fraxinum pennsylvanica*
Quaking aspen	*Populus tremuloides*
Red mulberry	*Morus rubra*
Silver maple	*Acer saccharinum*
Shore Plants	
Autumn olive*	*Elaeagnus umbellata*
Bittersweet nightshade*	*Solanum dulcamara*
Bull thistle*	*Cirsium vulgare*
Common privet*	*Ligustrum vulgare*
Field bindweed*	*Convulvus arvensis*
Highbush cranberry*	*Verbena trilobum*
Multiflora rose*	*Rosa multiflora*
Pampas grass*	*Phragmites autralis*
Purple loosestrife*	*Lythrum salicaria*
Queen Anne's lace*	*Daucus carota*
Reed canary grass*	*Phalaris arundinacea*
White sweet clover*	*Melilotus alba*
English plantain*	*Plantago lanceolata*
Velvet leaf*	*Abutilon theophrasti*
Blue vervain	*Verbena hastata*
Cinnamon fern	*Osmunda cinnamomea*
Common dodder	*Cuscuta sp.*
Common green briar	*Smilax rotundifolia*
Common milkweed	*Asclepias syrica*
Common ragweed	*Ambrosia artemisiifolia*
Daisy fleabane	*Erigeron annuus*
Elderberry	*Sambucus canadensis*

Table 4.4. Plant species, continued.

Fox grape	*Vitis labrusca*
Horse nettle	*Solanum carolinense*
Indian hemp	*Apocynum cannabinum*
Lambs quarters	*Chenopodium album*
Marsh milkwort	*Polygaga cruciata*
Mullein	*Verbascum thapsus*
Poison ivy	*Rhus radicans*
Prairie cordgrass	*Spartina pectinata*
Red-osier dogwood	*Cornus stolonifera*
Riverbank grape	*Vitis riparia*
Sensitive fern	*Onoclea sensibilis*
Spotted jewelweed	*Impatiens capensis*
Stiff goldenrod	*Solidago rigida*
St John's wort	*Hypericum perforatum*
Swamp milkweed	*Aesclepias incarnata*
Swamp rose	*Rosa palustris*
Tall meadow rue	*Thalictrum polygamum*
Virginia creeper	*Parthenocissus quinquefolia*
Virgin's bower	*Clematis virginiana*
Wild agrimony	*Agrimonia gryposepala*
Wild phlox	*Phlox pilosa*
Woodland sunflower	*Helianthus divaricatus*
Emergents	
Buttonbush	*Cepthalanthus occidentalis*
Broad leaved cattail	*Typha latifolia*
Chairmaker's rush	*Scirpus americanus*
Fox sedge	*Carex vulpinoidiea*
Horsetail	*Equisitum sp.*
Pondweed	*Potamogeton zosteriformes*
Soft rush	*Juncus effusus*
Sedge	*Carex sp.*
Swamp rose mallow, red & pink	*Hibiscus palustris*
Swamp smartweed	*Polygonum coccineum*
Submergents	
Coontail	*Ceratophyllum demersum*
Floating	
White water lily	*Nymphea odorata*

Rooted aquatic plants, or macrophytes, often compete with floating microscopic plants, or phytoplankton, for light and nutrients. In a lake with a large quantity of nutrients, algal blooms will occur if water is fairly turbid and high in phosphorus. In contrast, rooted plants are more likely to dominate in clearer water with lower levels of phosphorus. Turbidity can result from sedimentation from erosion of lakeshores or muddy tributary inflow, carp stirring the bottom as they feed, and high speed boat activity, among other things.

High turbidity in Galbraith Lake generally precluded dense growth of rooted aquatic plants. After the fishery renovation in 1972, lake water cleared somewhat and plants have recently grown in depths of eight to nine ft. Submergent and floating plants have predominated in depths of five feet or less and were particularly common on the west end of the lake with a narrower band on the north side (Table 4.5).

Table 4.5. Plant species found in Galbraith Lake, Marshall County, Indiana, during fisheries surveys from 1970 to 1991. Invasive exotic plants are listed first and indicated with an asterisk (*).

Common Name	**Pre-renovation - 1970** (location/depth in ft)	**Post-renovation - 1974** (location/depth in ft)
Emergents		
Cattail	margin/0-2	margin/0-2
Arrowhead	margin/0-2	margin/0-1
Water willow	margin/0-1	margin/0-1
Bulrush	margin	margin
Floating		
Spatterdock	margin/0-2	margin/0-2
White water lily	margin/0-2	margin/0-2
Submergents		
Curlyleaf pondweed*	rare/2-4	rare/2-4
Coontail	rare/2-4	rare/2-4
Algae		
Chara	rare	rare
Filamentous	scattered	rare
Total coverage	5%	--

Lists of species from the past 20 years all indicated low diversity of aquatic plants, but a systematic survey has not been conducted in recent years. Exotic species commonly dominate in lakes with high turbidity and nutrients. Curlyleaf pondweed is an exotic species that competes with native species by getting a head start in cooler waters of spring and early summer, tolerating low light conditions that reduce growth in most native species, and thriving on sediments enriched with organic matter. Warmer water temperatures in Galbraith Lake may contribute to the low coverage of this species. Although curlyleaf pondweed provides food for ducks and winter and spring habitat for fish and invertebrates, die-off of the plants in mid-summer can contribute nutrients through plant decay. If water clarity continues to improve, abundance and diversity of native species may increase and reduce existing stands of curlyleaf pondweed.

4.4 FISH

Public fishing is allowed in Galbraith Lake by the convent. Access without a fee is maintained at an undeveloped launching site adjacent to the county road on the south shore. Sport fishing was common 30 to 40 years ago, including ice fishing, but has been much reduced in the past 20 years (T. Fraiser, Ancilla Domini Convent, pers. comm.). Biologists from the Fisheries Section of IDNR have conducted fish surveys seven times since 1970 (Table 4.6). Although harvestable sport fish exist in the lake, the fishery is plagued by low water quality and abundance of exotics and other competing species. Fish were eliminated from the lake and restocked in the fall of 1972.

Table 4.6. Fish species found in and around Galbraith Lake, Marshall County, Indiana, in 1970-1991. Exotic fish species are indicated with an asterisk (*).

Common Name	1970	1973	1974	1976	1977	1978	1979	1991
Black bullhead				6				
Black crappie	40			91	26	36	257	
Bluegill	82	7	74	373	90	19	188	52
Bowfin			1		1	1	1	
Brook silverside	11							
Brown bullhead				5		1	1	
Carp*		5	5	3	68	117	43	9
Channel catfish		18	2					
Creek chub							1	
Gizzard shad	405			6		7	6	520
Golden shiner	1	8	24	939	486	228	27	
Grass pickerel							1	
Green sunfish	1		4	3	23	28		14
Lake chubsucker				1		2		
Largemouth bass	14	46	35	4	2	15	5	49
Pumpkinseed	10	1	37	53	145	111	201	81
Redear sunfish*		3	1	2				4
Spotted gar	5							
White crappie	1							2
White sucker			8	23	7	5	8	32
Warmouth	1							1
Yellow bullhead					2		1	1
Yellow perch	2							
Total number	570	88	191	1509	850	570	740	765
Total species	12	7	10	13	10	12	13	11

The most recent fish management report by IDNR indicated that "existing fish population is providing some recreational opportunities, [but] the Galbraith Lake fishery continues to be dominated by non-game species in 1991...similar to the situation found in the initial 1970 fishery survey" (Robertson, 1992). In 1991, largemouth bass growth was above average and weights were average. Weight and growth of bluegill was average in the same year. Only a few redear sunfish and white crappie were sporadically found in collections over a period of 20 years. Gizzard shad dominated the fish community in 1970 and 1991. Channel catfish were caught for several years and then disappeared after stocking them in 1972 and 1980. Three thousand five hundred channel catfish from 5-14 inches in length were again stocked in 1992.

High nutrient concentrations and productivity can result in winter fish kills due to low oxygen levels under ice. Winter fish kills occurred in Galbraith Lake during 1976-77 and 1977-78. High pH readings from 1973 to 1976 and the very shallow Secchi depth of 1 ft during the summer of 1976 suggested that algal productivity was extremely high in these years. Decomposition of organic matter from dying algae and plants may have contributed to the fish kill during the winter of 1976. The most recent fish kill was reported by the volunteer lake monitor, Tom Parsons, on April 22, 1990 (IDEM 1992). Dead gamefish, including bluegill, crappie, largemouth bass, and channel catfish, were found in the lake after ice-out during those years. Bluegill growth, condition, maximum size, and percent catchable were all lower than previously reported during these years. Carp were collected from the lake in every year after 1970 and probably entered the lake from downstream tributaries. Carp and golden shiners were most common in the years from 1976 to 1979.

Unlike game fish, which prefer dissolved oxygen concentrations above 4 mg/l in most waters and die at levels below 2 mg/l in the laboratory, both carp and golden shiners are notorious for their survival rates under low oxygen conditions. The lowest oxygen level at which golden shiners have exhibited 100% survival in the laboratory for 48 hrs was 1.4 mg/l and the highest concentration which killed all fish was 0.0 mg/l (Moore, 1942). Therefore, these species are likely to be the only ones which can survive severe winter fish kills. Small golden shiners provide excellent forage for game fish. However, larger adults prey on the bass fry (Hubbs, 1934).

Low dissolved oxygen concentrations can exacerbate toxic effects of other chemicals, in addition to directly killing fish. In general, oxygen saturation between 30 and 40% can increase toxicity more than 1.5-fold (Rand and Petrocelli, 1985). In Galbraith Lake, dissolved oxygen concentration fell below 40% at a depth of 12 ft in late summer. At reduced oxygen levels, the following chemicals become 1.5-2.5 times more toxic: ammonia, copper, lead, phenols (Lloyd, 1961), zinc (Pickering, 1968), surfactants (Hokanson and Smith, 1971), hydrogen sulfide (Adelman and Smith, 1972), and pulp mill effluent (Hicks and DeWitt, 1971). Even before killing the animal, lower levels of oxygen can result in reduced growth rates and deformities of eggs, young, and adults (Rand and Petrocelli, 1985).

Fisheries renovation and restocking have provided short-term benefits to sport fishing opportunities in Galbraith Lake, indicating that the lake can potentially support a reasonable fishery. Further renovations would be less effective due to lack of a fish migration barrier between Galbraith Lake and Flat Lake. Several fisheries reports recommended imposing a 14 inch minimum size limit for harvest of largemouth bass and stocking northern pike in order to sustain predation pressure on other species. However, long-term health of the fish community and success of stocking efforts will be strongly tied to techniques that will improve water quality.

4.5 IN-LAKE NUTRIENTS AND TROPHIC STATUS

Productivity in lakes is largely determined by relative amounts of phosphorus and nitrogen. Other nutrients are usually present in sufficient quantities and are less important in regulating populations. In general, water quality of Galbraith Lake has improved dramatically from having the lowest quality in the county (a rating of 75 on a scale of 5-75 in 1986) to having a better than average score for county lakes ranging from 16 to 40 acres in size (34 points in 1995 compare to an average of 43 points). However, levels of most forms of nitrogen and phosphorus in Galbraith Lake were still quite high in 1995, *especially in water at the bottom of the lake*, when compared to nutrient levels in larger lakes in Marshall County, Indiana (Table 4.7). Specific information on smaller lakes was not available from the IDEM reports.

Table 4.7. Water quality during the summer in Galbraith Lake during 1995 compared to other lakes of similar size in Marshall County, Indiana, during 1989 (IDEM, 1988-89; IDEM 1992-93). Lakes are listed from largest to smallest size. Surface and bottom readings are given for Galbraith Lake. Levels for all other lakes are averages of surface and bottom readings. One percent light depth was estimated as 2.7*SD for Galbraith Lake (after Cole, 1983). Values given are: size (acres), maximum depth (ft), nitrate, or NO^3 (mg/l), ammonia, or NH^3 (mg/l), organic nitrogen, or TKN (mg/l), dissolved phosphorus, or SRP (mg/l), total phosphorus (mg/l), pH, % of depth with 0.1ppm oxygen (oxic %), and depth at which one percent of light remains (1% ft). "G.L." = Galbraith Lake.

lake	size (ac)	max depth (ft)	NO^3 (mg/l)	NH^3 (mg/l)	TKN (mg/l)	SRP (mg/l)	tot-P (mg/l)	pH	oxic %	1% (ft)
Cook	93	52	1.43	1.65	1.28	0.22	0.27	8.0	20	6
Lawrence	69	63	2.83	1.12	1.28	0.12	0.16	6.9	50	14
Myers	96	59	2.21	0.69	0.94	0.13	0.15	7.6	56	19
Pretty	97	40	0.91	0.03	1.01	0.01	0.06	8.1	82	29
G.L. surface	37	29	<0.1	<0.1	1.00	0.02	0.12	8.8	47	11
G.L. bottom	--	--	<0.1	5.6	6.60	0.10	2.58	7.1	--	--
average	**89**	**54**	**1.85**	**0.87**	**1.13**	**0.12**	**0.16**	**7.7**	**52**	**17**

4.5.1 Seasonality of physical and chemical characteristics

Weather and biological activity seasonally alter physical and chemical characteristics of lakes. Physical and chemical measurements from Galbraith Lake show distinct differences between surface and bottom water, as well as between late summer and early fall (Table 4.8). Surface pH, temperature, and dissolved oxygen decreased from summer to fall. These changes are induced by weather and plant productivity and were addressed above. Ammonia, organic nitrogen, and especially total phosphorus increased at the surface during the same period (Figure 4.8). These nutrients will be discussed individually.

Table 4.8. Water quality parameters measured in Galbraith Lake, Marshall County, Indiana, in mid-summer (August 7,1990, August 8, 1995, and August 16, 1995) of three years and fall (September 22, 1995) of one year. Numbers in bold typeface indicate readings that were higher than average Marshall County lakes. Data from August 7, 1990 and August 1, 1995, were collected through the IDEM Clean Lakes Program.

	8/7/90*		**8/1/95**		**8/16/95**		**8/22/95**
parameter	surface	bottom	surface	bottom	surface	bottom	surface
dissolved oxygen (mg/l)	9.6	0.2	---	---	10	0	5
pH	**9**	7	9.3	7.3	**8.8**	7.1	**8.2**
temperature (^{O}F)	74	46	---	---	84	55	65
ammonia (mg/l)	0.01	**11.9**	0.004	**7.3**	<0.1	**5.6**	0.2
nitrate/nitrite (mg/l)	0.79	5.7	0.007	0.007	<0.1	<0.1	<0.1
organic nitrogen (TKN)	**1.76**	**6.030**	1.04	2.32	1	**6.6**	**1.2**
dissolved phosphorus (SRP)	0.005	0.02	0.002	1.09	0.02	0.10	<0.01
total phosphorus (mg/l)	0.05	0.05	0.035	**1.34**	0.12	**2.58**	**0.8**
conductivity (umhos)	419	460	438	472	---	---	---
alkalinity (CO^3/l)	117	290	100	238	---	---	---

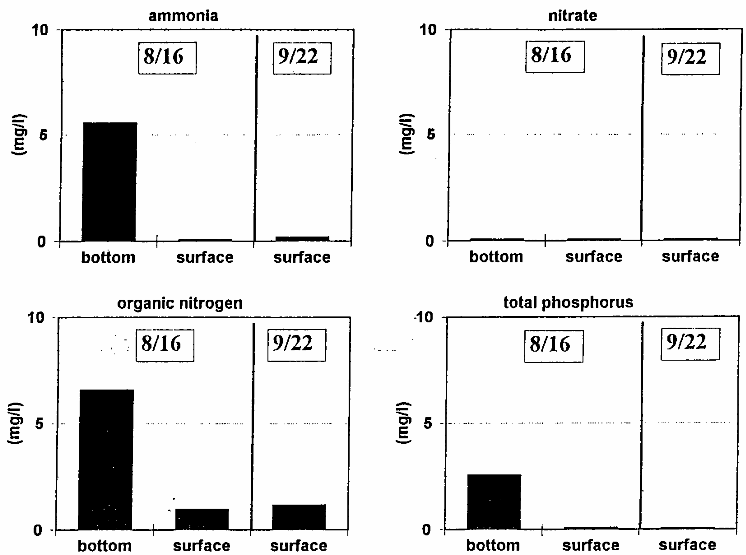
4.5.2 Nitrogen levels

Three forms of nitrogen are commonly measured in lake ecosystems. Microbial, plant, and animal activity convert the various forms of nitrogen into each other in a nitrogen cycle. Nitrogen originates from the watershed and can be recycled many times within the lake before conversion to nitrogen gas and consequent loss to the atmosphere.

Organic nitrogen, or TKN, is a combination of proteins and other materials resulting from excretion or decomposition of plant and animals. Organic nitrogen is generally not available as a plant nutrient until broken down further by bacteria and fungi, but can be an excellent nitrogen source for algae growth (McCarthy, 1972). Organic nitrogen was unusually high in deeper water (6.6 mg/l) and may be a result of previously high levels of productivity in the lake.

Nitrate is the most common form of inorganic nitrogen and enters lake systems through runoff from the watershed. Nitrates are usually highest in oxygenated parts of the lake, as microbes rapidly convert nitrate to nitrite and then to nitrogen gas in deoxygenated parts of the lake or converted to ammonia in oxygenated portions. This is the main process by which nitrogen is removed from lake systems. Nitrate levels in Galbraith Lake (<0.10 mg/l) were well below average for other lakes in the county and

Figure 4.8. Ammonia, nitrate, organic nitrogen (TKN), and total phosphorus at the surface and bottom of Galbraith Lake on August 16, 1995 and at the surface on September 22, 1995.



may be an indication of high microbial activity in the large deoxygenated portion of the lake in the summer.

Ammonia is a form of nitrogen that plants can readily use for growth. Only legumes and some species of bluegreen algae avoid the need for ammonia because these plants can convert nitrogen from the air. Fall turnover brings these nutrients to the surface, where bluegreen algae and other plants use the nitrogen. During the fall, the explosion in the phytoplankton species *Mycrocystis* corresponded to a dramatic decrease in ammonia levels. Unlike other species of bluegreen algae which convert nitrogen from the air, *Mycrocystis* must use ammonia as the primary source of nitrogen.

At high concentrations, ammonia is poisonous to fish and other animals, including humans. Ammonia levels of 0.5-4.6 mg/l killed 50% of bluegill within 96 hours in laboratory tests (Roseboom and Richey, 1977). Other species native to Indiana showed similar intolerance to high ammonia levels. Low nitrate and high ammonia levels are common at the bottom of eutrophic lakes in late summer. However, the level of ammonia in the bottom of Lake Galbraith was high enough to be of concern at 5.6 mg/l and could cause fish kills if summer storms resulted in lake turnover.

Sources of nitrogen in lakes are varied, diffuse, and generally difficult to control. Major natural sources of organic nitrogen (TKN) and ammonia in the hypolimnion are excretion and decay from organisms in the epilimnion. The concentration of nutrients at the bottom of the lake may be a remnant of previous extremely high levels of productivity in the lake. Common sources of ammonia also include fertilizers and manure in agricultural runoff, lawn chemicals, and sewage inflows.

4.5.3 Phosphorus levels

Phosphorus generally acts as the main limiting agent for biological productivity in most lake systems. Both green and bluegreen algae are dependent upon phosphorus present in the water for growth. Levels of total phosphorus above 0.02-0.03 mg/l indicate eutrophication in temperate North American lakes (U.S. EPA, 1980). Levels of phosphorus in Galbraith Lake were three times lower in 1995 than in 1986 (0.43 to 0.14 mg/l). Like other nutrients in the lake, total phosphorus levels at the surface were at or below average for other Marshall County lakes, but remained quite high at the bottom (2.58 mg/l). The increase in total phosphorus at the surface in the fall sample probably indicated that higher concentrations in deeper water were beginning to mix with lower concentrations in surface waters during turnover.

Ortho-phosphorus levels indicate the amount of phosphorus that is dissolved in the water column and is immediately available for use by algae. Low levels of ortho-phosphorus may indicate low input of phosphorus from the watershed or that most of the available phosphorus is rapidly removed from the water by highly productive algae. Soluble phosphorus (ortho-phosphorus as PO_4) levels ranged from 0.01 to 0.22 mg/l in other Marshall County lakes under 100 acres in size. While the level of soluble phosphorus was 0.02 mg/l at the surface and 0.1 mg/l at the bottom in late summer (August 16), the levels were not detectable at the surface and were not measured at the bottom in fall (September 22), 1995. These levels were within the range of other lakes in the county.

Because sources of phosphorus are fewer and more easily controlled than nitrogen, most lake restoration efforts focus on this nutrient. Phosphorus loading may be from external or internal sources. Agricultural runoff and human waste from sewage outfalls may contribute phosphorus from the watershed. Because phosphorus readily attaches to soil particles, sedimentation can bring phosphorus into the lake where it becomes concentrated in lake sediments. Under low oxygen or high pH conditions, phosphorus detaches from the sediment and becomes available for plant use. During summer storms or spring and fall turnover, phosphorus in deep waters can be transported to surface water, where it can cause periodic algal blooms. Therefore, effects of phosphorus may be controlled by reducing inputs or using chemical or physical means to lock the phosphorus into the sediments.

5.0 TRIBUTARY ASSESSMENT

While some nutrients present in the lake are repeatedly cycled from internal sources, most of the nutrients probably enter the lake from external sources via tributaries and overland flow. Galbraith Lake receives input from a intermittent flowing stream on the east side of the lake, intermittent flow from small channels through a wetland area on the west side, and seven storm drains that enter on the north side. The lake outlet is located on the southwest side and runs past a small sewage treatment plant for Ancilla College and convent. Samples from the upper outlet were taken immediately below the lake and the lower outlet samples were located as the stream exited a cattle pasture that surrounded the sewage treatment plant. In general, nutrient inputs dropped, sometimes precipitously, from late summer to early fall (Table 5.1; Figure 5.1).

Figure 5.1. Ammonia, nitrate, organic nitrogen (TKN), and total phosphorus in tributaries to and the outlet stream from Galbraith Lake on August 16, 1995 and on September 22, 1995. The upper outlet section was not sampled in August. The west inlet was too dry to sample in September. (east = east inlet; west = west inlet; storm = storm water drain; lower = lower outlet; upper = upper outlet)

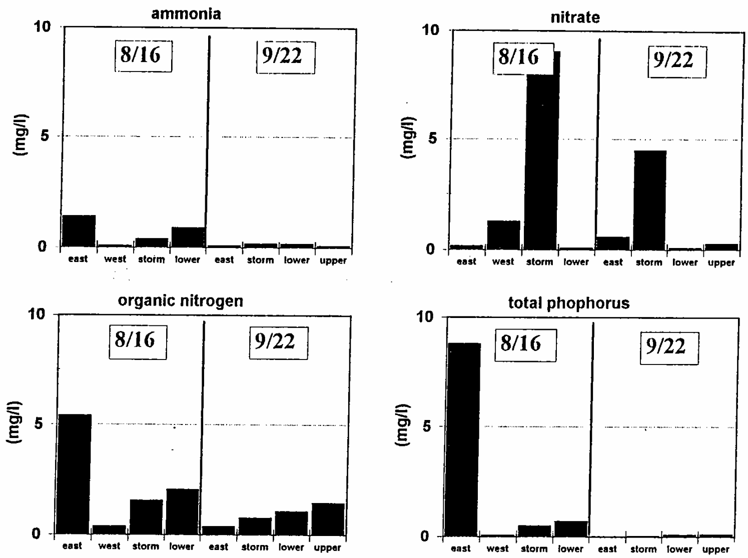


Table 5.1. Water quality parameters measured at several sites in Galbraith Lake, Marshall County, Indiana, and surrounding tributaries in late summer (August 16) and fall (September 22), 1995. Numbers in bold typeface indicate readings that were at or above average Indiana stream values for: a) total phosphorus at 0.17 mg/l; b) turbidity, or total suspended solids (TSS) at 38 NTU; and c) nitrate at 4.5 mg/l (IDEM, 1991).

A. August 16, 1995

parameter	storm drain	east inlet	west inlet	lower outlet
dissolved oxygen (mg/l)	7.5	1.5	4.5	1.5
oxygen saturation (%)	82	19	45	19
pH	6.8	6.1	7.0	7.2
temperature (^{O}F)	67	80	60	83
ammonia (mg/l)	0.4	**1.4**	0.1	0.9
nitrate/nitrite (mg/l)	**9**	0.2	1.3	<0.1
organic nitrogen (TKN)	1.6	5.4	0.4	2.1
total phosphorus (mg/l)	**0.52**	**8.78**	0.09	**0.74**
turbidity (NTU)	3.0	4.5	4.3	4.7

B. September 22, 1995

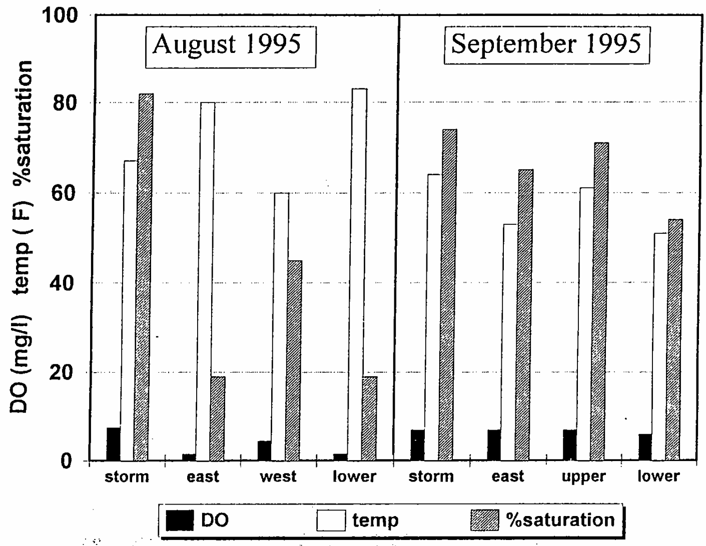
parameter	storm drain	east inlet	west inlet	upper outlet	lower outlet
dissolved oxygen (mg/l)	7	7	---	7	6
oxygen saturation (%)	74	65	---	71	54
pH	7.4	7.4	---	8.1	7.2
temperature (^{O}F)	64	53	---	61	51
ammonia (mg/l)	0.2	0.1	---	<0.1	0.2
nitrate/nitrite (mg/l)	**4.5**	0.6	---	0.3	<0.1
organic nitrogen (TKN)	0.8	0.4	---	1.5	1.1
total phosphorus (mg/l)	0.06	<0.03	---	0.15	0.12
turbidity (NTU)	---	---	---	---	---

5.1 Siltation, temperature, and dissolved oxygen

Turbidity in the inlet and outlet streams was extremely low when measured in the summer and fall. However, sediment had half filled the culvert for the east inlet, suggesting that at some time in the year, siltation from this inlet is probably very high. The substrate in the outlet stream had a soft silt consistency. The origin of silt in either stream was not specifically known.

Temperature of water in the storm drain and west inlet was 20^{O}F cooler than that of the east inlet, outlet, and lake surface, and only 5 to 12 degrees higher than the bottom of the lake (Figure 5.2). Samples from the west inlet were taken in a temporary pool in

Figure 5.2. Dissolved oxygen, temperature, and oxygen (%) saturation in tributaries to and the outlet stream from Galbraith Lake on August 16, 1995 and on September 22, 1995. The upper outlet section was not sampled in August. The west inlet was too dry to sample in September. (east = east inlet; west = west inlet; storm = storm water drain; lower = lower outlet; upper = upper outlet)



the channel that had little flow and was surrounded by forested wetland. Cooler groundwater probably constitutes most of the flow in both the west inlet and especially in the storm drain. High temperatures in the east inlet may be a result of surface and shallow tile drainage through heated soil with little vegetative cover.

Oxygen saturation was low in the east inlet during the summer and consistently low in the lower portion of the outlet stream. Low oxygen may indicate decomposition of organic matter or pollutants and typifies a relatively slow moving stream with little physical complexity, such as stones and logs, that would create turbulence and introduce oxygen.

5.2 Nitrogen levels

Inlets appeared to be a major source of nitrogen for Galbraith Lake. In late summer, relatively high levels of ammonia and organic nitrogen were found in the east inlet, which drains an agricultural watershed. Ammonia and organic nitrogen were also elevated as the outlet stream left the pasture area in comparison to the source at the lake. The east inlet registered an ammonia level which approaches the levels of concern (1.5 mg/l) in the Illinois water quality standards, but was nearly half the 2.5 mg/l level cited for support of indigenous aquatic life from April-October (Illinois Pollution Control Board, 1982).

Nitrate levels in the storm drain were measured at 9 mg/l in late summer, approaching the drinking water standard of 10 mg/l, but had fallen by 50% in the early fall sample to average Indiana stream levels (4.5 mg/l). While other nitrogen forms decreased in inlets and the outlet, nitrate levels in the east inlet increased somewhat in the fall, but remained at a relatively low level.

5.3 Phosphorus levels

Phosphorus flow through Galbraith Lake appeared to be very high. Total phosphorus in the east inlet was 3.4 times the concentration found in bottom samples and 55 times the concentration of an average Indiana stream. Total phosphorus was also elevated downstream along the outlet waterway and in the stormwater drain in late summer. All of the sites showed relatively low levels of total phosphorus in early fall with the highest readings in upper and lower portions of the outlet stream. However, all measurements exceeded the Illinois water quality standard of 0.05 mg/l total phosphorus, except for the east inlet in the fall (Illinois Pollution Control Board, 1982). Soluble phosphorus was not detectable (<0.01 mg/l) in any stream samples.

6.0 RELATIONSHIP BETWEEN NUTRIENTS AND PRODUCTIVITY

Unlike most terrestrial ecosystems, where nitrogen tends to be the limiting agent, productivity in most freshwater ecosystems is limited by the amount of available phosphorus. Both green and bluegreen algae are dependent upon phosphorus present in water for growth. In contrast, several species of bluegreen algae function similarly to legumes; they are capable of fixing nitrogen from the air and do not rely on ammonia in the water. The Eutrophication Index, developed by IDEM, provides a convenient format for comparing and scoring various aspects of productivity and lake condition. This index ranges from 0 to 75 with the higher scores indicating more eutrophication, productivity, or lake aging.

The ratio of nitrogen to phosphorus indicates which nutrient is controlling productivity in a particular lake. Depending upon the species, algae generally require a ratio of total nitrogen to total phosphorus of 15:1 (U.S. EPA, 1980). Ratios of 10:1 or less indicate nitrogen limitation or overabundance of phosphorus. Adding concentrations for all forms of nitrogen gives a total nitrogen concentration of 6.75 mg/l and total phosphorus concentration of 1.35 mg/l, as an average of surface and bottom measurements in Galbraith Lake (Table 6.1). Therefore, the ratio of total N to total P was five, suggesting an overabundance of phosphorus relative to the amount of nitrogen. However, in Galbraith Lake, both nutrients are present at very high levels in deeper water during the summer.

Table 6.1. Calculation of the Eutrophication Index in Galbraith Lake, Marshall County, in (A) mid-summer, August 8; (B) late summer, August 16; and (C) fall, September 22, 1995. Because bottom samples were not taken in September, some values were estimated for September on the basis of August data or related September information and are indicated below by an asterisk (*). Where available, points for nutrients are assigned for average concentration. Data for August 7, 1990, and August 1, 1995, were collected through the IDEM Clean Lakes Program.

	A	B	C	D
	8/7/90[&]	8/1/95[&]	8/16/95	9/22/95
Parameter	points	points	points	points
1. Total phosphorus (ppm)	**2**	**4**	**5**	**3***
A) 0.05 ave				
B) 0.035/1.34 (0.69 ave)				
C) 0.12 at surface (1.35 ave)				
D) 0.08 at surface				
2. Soluble phosphorus (ppm)	**0**	**4**	**5**	**3***
A) 0.01 ave				
B) 0.002/1.088 (0.545 ave)				
C) 0.3 at surface (1.0 ave)				
D) 0.0 at surface				
3. Organic nitrogen	**4**	**3**	**4**	**4***
A) 3.89 ave				
B) 1.037/2.321 (1.679 ave)				
C) 1 at surface (3.8 ave)				
D) 1.2 at surface				

Table 6.1. Calculation of the Eutrophication Index, cont.

4. Nitrate	**4**	**0**	**0**	**0**
A) 3.26 ave				
B) 0.007/0.007 (0.007 ave)				
C) <0.1				
D) <0.1				
5. Ammonia	**4**	**4**	**4**	**4***
A) 5.96 ave				
B) 0.004/7.285 (3.65 ave)				
C) <0.1 at surface (2.85 ave)				
D) <0.1 at surface				
6. DO (% saturation at 5 ft)	**1**	**4**	**0**	**0**
A) 114.25%				
B) 157%				
C) 108%				
D) 5mg/l at 18 C = 53% at surface, probably lower at 5 ft				
7. DO (% of column with 0.1 ppm)	**3**	**2**	**3**	**4***
A) 47.1%				
B) 50%				
C) 47%				
D) probably zero by 6 ft = 21% of column				
8. Light penetration	**6**	**6**	**6**	**6**
A) Secchi depth = 2.95 ft				
B) Secchi depth = 2.95 ft				
B) Secchi depth = 4.1 ft				
C) Secchi depth = 3.8 ft				
9. Light transmission	**3**	**4**	**4***	**4***
A) 42%				
B) 29%				
C) 26% (estimate based on Secchi depth)				
D) 23% (estimate based on Secchi depth)				
10. Total plankton / mL (to 1% light)	**1**	**1**	**2**	**5**
Bluegreen dominance	**10**	**10**	**0**	**10**
A) 3,544 / L; 86% bluegreen				
B) 5,348 /L; 88% bluegreen				
B) 8,853 / L; 45% bluegreen				
C) 36,064 / L; 83% bluegreen				
Total score	**38**	**42**	**33**	**43**

Location of nutrients in the lake affect the availability and timing of productivity. Nitrogenous compounds differed dramatically between surface and bottom waters in Galbraith Lake. Surface waters across the lake appear to be fairly well mixed. Surface water at the public access site had a total phosphorus level of 0.15 mg/l, which was slightly higher than the surface reading over the deepest part of the lake. All other readings were the same at the public access site and over the deepest part of the lake.

Surface (epilimnion) levels of all nitrogen and phosphorus forms were relatively low. Organic nitrogen (TKN) and ammonia were quite high at the bottom (hypolimnion) in late summer. Both organic nitrogen (TKN) and total phosphorus increased at the surface in September, possibly as a result of initial mixing during fall turnover. If so, phosphorus levels probably increase even more later in the fall.

7.0 CONTROLLING NUTRIENTS AND PRODUCTIVITY

The status of a lake should be gauged relative to regional and historical context of the lake. Geologic history and climate of the lakes in northern Indiana predisposes these lakes to the eutrophication process. Therefore, the goal of lake management in this region is not necessarily to eliminate productivity, but to prevent an unacceptable acceleration in the aging process to the point that desired values and uses of the lake are impaired. Degradation in habitat for native species of plants and animals, as well as human recreational and domestic use of water supplies may be of concern. Priorities for restoration and improvement of Galbraith Lake are dependent upon the desired values and uses of the lake and surrounding watershed.

Water quality in Galbraith Lake was extremely poor in the 1970s and 1980s, with water clarity readings of one or two feet from 1970 to 1986 and the highest possible EI score in 1986. However, the quality of Galbraith Lake appears to have stabilized at a much higher level of quality over the past decade (Table 7.1). Both the class and management category have changed from indicating a severe water quality problem, in which drastic and expensive restoration measures were recommended, to an intermediate level of water quality impairment in which particular sources of nutrient and sediment impacts may be targeted for control.

Table 7.1. Water quality and management group trends over ten years (1986-1995) in Galbraith Lake, Marshall County, Indiana.

parameter	1986	1990	1995
total phosphorus (mg/l)	0.43	0.05	0.035 / 2.58$^{\tau}$
Secchi depth (ft)	1.0	3.0	4.1
eutrophication index (EI)	75	38	33-43
lake class	III	II	II
management category	IVB*	VIIB**	VIIA**

$^{\tau}$Lowest level of total phosphorus at the surface and highest level at the bottom are given.
*Group IVB - Relatively shallow lakes with the poorest water quality.
**Group VIIB and VIIA - Relatively shallow lakes with intermediate water quality.

The Eutrophication Index (EI) can be used to identify the most serious problems and set goals for improving water quality in lakes. Compared to other lakes of similar size in Marshall County, Galbraith Lake has moved from eighth position out of eight lakes to fifth highest--and about average--quality over the past decade (Table 7.2). Significant parameters related to nutrient load and water clarity improved for Galbraith Lake, but were not much improved relative to other lakes, changing from the highest to the third highest phosphorus concentration and remaining at the lowest water clarity (Secchi depth). Management Group V contains relatively shallow lakes with the best water quality in Indiana. To enter this category and be the highest quality lake in the county, the eutrophication index would need to be halved again to an EI of 18.

Table 7.2. Water quality of Galbraith Lake compared to other lakes of similar size in Marshall County, Indiana, in 1986 (IDEM, 1988-89). Lakes are listed from highest overall quality, as indicated by a low Eutrophication Index (EI), to lowest quality and high EI. The Eutrophication Index ranges from 5 (low productivity) to 75 (high productivity) and are usually sampled in mid-summer. Average measurements are given for three sample dates in 1995.

lake	trophic class	size acres	max depth (ft)	mean depth (ft)	tot-P mg/l	Secchi (ft)	EI	management group
Holem	I	30	74	0.8	0.03	8.5	23	VIIA
Dixon	II	33	48	14.5	0.26	7	30	VIIB
Kreighbaum	II	20	28	20	0.07	11	32	VIIA
Flat	II	26	24	8.1	0.16	6	35	VIIA
Galbraith ('95)	**II**	**37**	**27**	**13**	**0.08***	**3.6***	**39***	**VIIA**
Eddy	II	16	49	25	0.09	5	42	VIA
Thomas	III	16	58	15	0.06	4.5	51	IVB
Hawks	III	40	9	4	0.1	5	65	IVB
Galbraith ('86)	**III**	**37**	**41***	**13**	**0.43**	**1**	**75**	**IVB**
County average	**II**	**28**	**40**	**13**	**0.15**	**5.8**	**43**	**---**

*The maximum depth listed for Galbraith Lake in 1986 was probably a typographical error.

The quality of Galbraith Lake may degrade somewhat when deeper water mixes with surface water during spring and fall turnover. Sampling for calculation of the Eutrophication Index (EI) is generally conducted at the same time of year (mid-summer) to facilitate comparisons between lakes. Late summer and early fall 1995 estimates for the EI at Galbraith Lake showed a drop in water quality by 30% later in the season. Surface water levels of phosphorus decreased. (Unfortunately, no deep water sample was obtained in the fall.) The reduction in surface phosphorus was accompanied by a dramatic increase in the dominance of bluegreen algae. These algae are probably thriving on the available phosphorus.

If deep water nutrient levels were reduced to that of surface waters, the EI could drop by at least 7 points to a score of 26. (Class I, or highest quality, lakes must have an EI of less than 26.) Therefore, the most effective management strategies could include: a) reducing sediment and nutrient inputs to the lake; b) removing nutrients from deeper water in the lake; c) avoiding the mixing of deep water with surface water during biologically important times of the year, such as spring and summer; d) aerating deeper water to prevent release of phosphorus; and e) sealing nutrients into the lake bed.

7.1 Reducing sediment and nutrient inputs

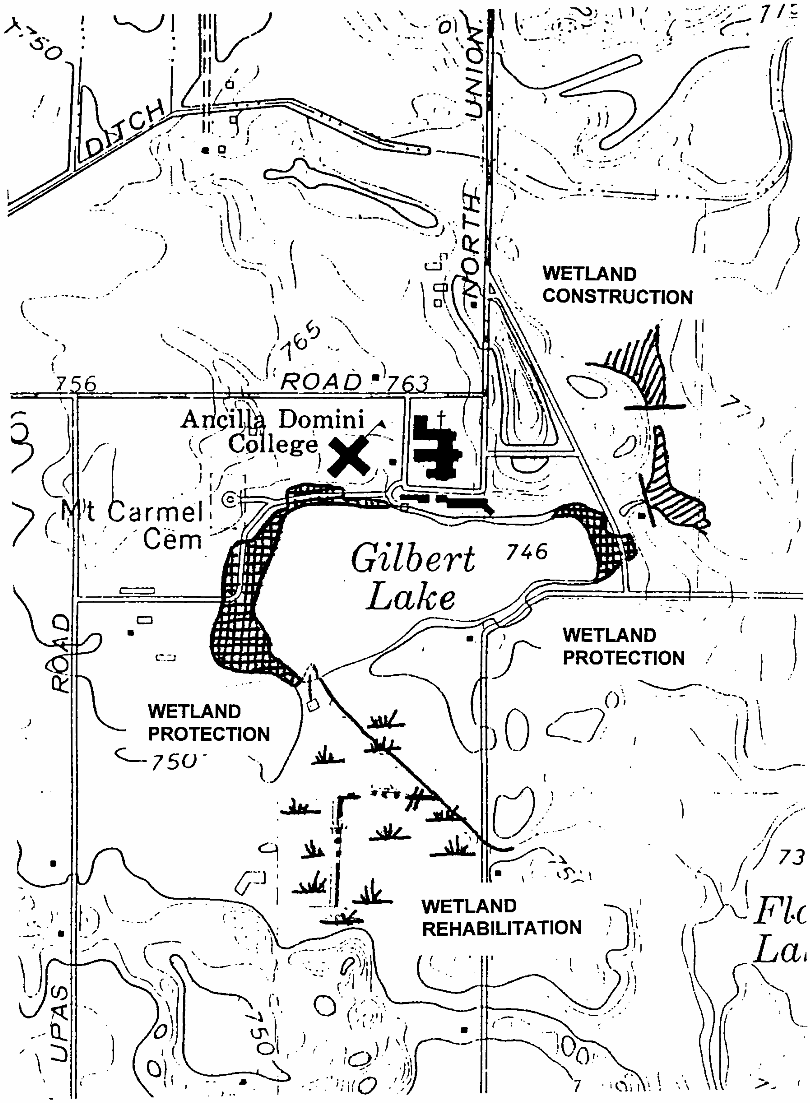
Sediment and nutrient sources to Galbraith Lake are located immediately around the lake and in the watershed. Beneficial activities may include: 1) maintenance of aquatic vegetation in shallow bays on the east and west ends of the lake; 2) rehabilitation of the channelized outlet stream and associated wetlands; 3) routing wastewater discharge through a wetland and into the outlet stream on the south side of the lake; 4) providing adequate protection from cattle for restoration measures around the outlet stream and on the southwest side of the lake; 5) control of siltation and nutrients in the eastern inlet through construction of a sediment trap or wetland area; and 6) identification and minimization of nutrient sources in storm water drains (Figure 7.1).

Growth of emergent and submergent plants in the shallow **eastern and western bays and associated shorelines** will assist in nutrient uptake and sediment control. These plants should be protected. Boating in shallow areas of the lake should be avoided, and the shoreline of these bays is not developed, so heavy growth of plants in these areas should not interfere with recreational use of the lake. Access by cattle may need to be controlled to reduce or eliminate grazing on young, susceptible wetland plants on the western edge of the lake. Expansion of purple loosestrife should be controlled by carefully digging plants to retrieve the entire root or cautiously spot treating plants with appropriate chemicals.

Previous channelization of the **outlet** reduced habitat complexity in the stream and caused increased velocity and erosion. Planting and maintenance of shrubs and trees along the outlet stream could increase stabilization of the banks, reduce heating during summer, and may decrease sediment and nutrient transport to the stream. Eventually, cleaner substrate and stable meanders would provide more diverse habitat for stream dwelling species. Restoration or enhancement of the wetland area around the outlet may be accomplished by controlling flow in the lateral tile to the outlet stream.

The pretreatment **wastewater plant** discharges directly into the lake from a 0.25 acre lagoon that acts as a finishing pond. Effects of the discharge are probably much less severe than before pretreatment was installed. However, rerouting of discharge water through a small wetland and into the outlet stream in the low-lying wooded area on the

Figure 7.1. Map of proposed wetland protection or enhancement measures. (Potential wetland construction areas are indicated with hatch marks. Potential wetland protection areas are indicated with grid marks. Potential wetland rehabilitation areas are indicated with wetland plant symbols).



southwest corner of the lake may provide further water quality benefits to the lake and outlet stream, as well as offering habitat for wetland species.

Access by **cattle** on the southwest portion of the lake was been significantly reduced as of 1993, which has undoubtedly increased water clarity on that side of the lake. However, there is still some damage due to trampling around the outlet stream, including steep eroding banks in some sections of the stream and a soft silty substrate. Lower sections of this stream (near South Union Road) showed unusually low dissolved oxygen levels and somewhat elevated ammonia and phosphorus during late summer. Grasses and low-lying vegetation along the stream appeared to be in fairly good condition. Protected plantings of trees along the stream would eventually provide shade, reducing late summer water temperatures and increasing oxygen levels and nutrient processing. Allowing the stream to reconstruct meanders and rehabilitation of wetlands around the stream will also provide additional time for settling and removal of sediment and nutrients derived from activities of the cattle.

Phosphorus and organic nitrogen inputs were high and late summer dissolved oxygen levels were low in the **eastern inlet**. Visual observations of sediment in the culvert at the inlet indicated that erosion from the watershed or channel may require assessment and control. Maintenance of riparian buffer strips along the stream will control sediments and nutrients and lower summer heating of the stream. Construction of a small wetland or sediment basin in one of two possible locations may remove a significant proportion of the sediment and nutrients in the inlet. As a rule of thumb, an effective treatment wetland would cover 1 to 5 percent of the watershed area (Kadlec and Knight 1996). In this subwatershed, which contains about 110 acres (44.5 ha) or 60 percent of the total Galbraith Lake watershed and most of the agricultural land, the equivalent would be a wetland covering 1.1 to 5.5 acres (0.45-2.2 ha).

The **storm drains** on the north side of the lake exhibited extremely high nitrates and elevated phosphorus concentrations. Nitrates are not common in open water, due to uptake by microbes and plants, but are generally present in groundwater. (The drain is essentially functioning as a groundwater source.) Fertilizer application or sewage connections could increase nitrate and phosphorus content of drain water. Management of timing and application rates of fertilizers on lawn areas in order to increase uptake by plants and decrease runoff may reduce nutrients in the storm drains. More information on the route of water into these storm drains may pinpoint the sources of nutrients.

7.2 Removing nutrients from deeper water

Two goals could be accomplished by pumping deep water from the lake to irrigate grounds and gardens around Ancilla College. Highly concentrated nutrients would be removed from the lake, taken up by landscape or garden plants, and water would return via groundwater or runoff. Outside inputs due to runoff from fertilizer would be eliminated or reduced. Deep water in Galbraith Lake would have an N:P content of 5:1. Supplemental fertilizers with no additional nitrogen or phosphorus and appropriate quantities of potassium could be used. However, soils should be tested for nutrient content prior to supplying additional fertilizer to the grounds. Harvesting of gardens would completely remove the nutrients from the watershed system, whereas lawn clippings would eventually decompose and return the nutrients to the lake through runoff.

7.3 Avoid mixing of deep and surface water

Natural and artificial causes, including fall turnover, wind, operation of power boats, and disturbance of the lake bed during construction activities, can mix low quality deep water with higher quality surface water in shallow lakes. Fall turnover is inevitable and cannot be minimized by management activities. High winds during summer storms can cause mixing in shallow lakes. The longest fetch in Galbraith Lake runs east to west. Winds from these directions would build up the most energy and have the greatest effect on lake mixing. Therefore, preservation and reforestation on the east and west ends of the lake would partially shelter the lake from wind and may limit detrimental mid-summer mixing in shallow areas of the lake.

Power boats should not be operated in water less than 15 ft deep to avoid stirring bottom sediments and resuspending nutrients. Total phosphorus can increase from 16-73 percent with boating activity on shallow lakes; increasing motor power from 10 hp to 50 hp increases sediment suspension capability by 150-250 percent (Yousef, et al., 1979). Therefore, only nonmotorized watercraft should be used along the eastern basin of the lake and western shoreline. Low horse power motors operated at low (trolling) speed would be acceptable in other parts of the lake.

The lake bed in Galbraith Lake probably contains a high level of attached phosphorus and other nutrients. Construction activities that require disturbance of lake sediments should be avoided. If such activities are necessary, use of silt curtains and other sediment control measures should be incorporated in the construction process to minimize resuspension of sediments and nutrients in the lake. Submergent and emergent plants stabilize lake sediments and should not be disturbed with the exception of activities associated with removal of purple loosestrife.

7.4 Aerating deeper water

Sediment oxidation with calcium nitrate injection or aeration of deeper waters can prevent release of phosphorus by increasing oxygen levels at the bottom of the lake. Decreasing water quality at turnover in Galbraith Lake suggests that the costs of aeration would likely offset any benefits. Mechanical aerators tend to be expensive and would probably cause detrimental resuspension of nutrients in deeper waters of Galbraith Lake.

7.5 Sealing nutrients into the lake bed

Sediments can be treated within the lake by chemical means. Aluminum oxides (alum) will bind phosphorus and eventually create a seal over the sediments. Alum treatments can be applied directly to the lake or injected into inflows. Alum can be potentially toxic under acidic conditions, but is not likely to be a problem in the hardwater conditions of Galbraith Lake. If a fisheries renovation is attempted in the future, lake managers may consider alum treatment prior to restocking the lake.

7.6 Conducting future research

Information obtained during this study points to a number of low cost management activities that would improve the condition of the lake under any circumstances. However, additional information may be required to predict effectiveness of more costly management alternatives. Future research on the lake could include: a) continued participation in the IDEM Volunteer Lake Monitoring Program to provide an ongoing data on water clarity, algae concentration, and nutrients; b) chemical testing of tributaries and storm drains after a series of heavy rains; c) biological sampling of macroinvertebrates in the main tributary and outlet stream; d) a complete survey of aquatic plant species distribution and abundance; e) testing for fecal coliforms at the public access site, boat dock, and outlet stream; f) identification of nutrient sources in the storm drains; and g) sediment analysis for phosphorus content.

8.0 CONCLUSION

Galbraith Lake experienced a period of time from the 1960s to the 1980s when water quality was severely degraded. A number of steps have been taken to decrease nutrient loading to the lake and rehabilitate the fishery during the past decade. Not all of these activities have been a complete success. However, water quality in the lake has shown significant improvement during the past several years of testing. Additional steps are possible at minimal cost which could pave the way for further improvements in fishing and other recreational use of the lake.

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